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Science and Medicine of Exercise and Sports

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To Doug

SCIENCE AND MEDICINE OF
EXERCISE AND SPORTS

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Preface

In recent years great progress has been made in the scientific study of exercise and sports In particular, exercise physiology has far outstripped the other research areas dealt with in this symposium because its implications are so numerous for fields ranging from physical education athletics, and medicine to industry and the military Still quite different approaches have been made to the study of exercise and sports Consequently, when viewed from the perspective of the subject as a whole—as it is represented in this symposium—the research activities generally have tended to be highly compartmentalized even within specialized areas, and lacking in synthesis

The motives of the researchers who have applied their thinking to exercise and sports have been at least as different as their fields of specialization Thus, some investigators have been intent upon finding ways to extend the limits of human performance in something of the spirit of a musician, gymnast, or mountain climber, and to them no end beyond achieving a new perfection or breaking an athletic or sports record has been sought As they have seen it, the challenge is there and it must be met

Other investigators have utilized exercise and sports research as a means of contributing to the growing fund of knowledge of human performance and behavior under various experimental conditions In some instances of this type of research, the investigator has been led inexorably by his own curiosity wherever it might draw him, regardless of possible applications of his discoveries, and perhaps he has had little immediate concern whether his findings would ultimately help someone run a faster mile, work more efficiently, learn skills more rapidly, or respond more quickly to therapy

In still other instances the investigator has been interested in the measurable effects of various types of prescribed or freely selected physical activity Perhaps he has experimented with the effects of exercise and sports upon children and youth so as to design more effective physical education curricu

lums, has studied the effects of physical training as it might apply in athletics, military combat, or space travel, has tested the response of muscles to various exercise dosages in order to define prescriptions for orthopedic, geriatric, or circulatory therapy, or perhaps he has examined the competitive sports situation to gain insight into human motivation In any case he has approached the problem and has coped with it from the vantage point of his own interest and with the skills of his particular specialization

Slowly, as carefully gathered data has accumulated, a mosaic of the entire field of exercise and sports seems to be forming At present, the amount of work that has been done which throws light upon various phenomena related to exercise and sports is impressive and encouraging But it is also bewildering Research workers have of course published their findings in their own journals, with the result that information pertinent to exercise and sports is scattered through a vast literature ranging from the anthropological, chemical, physiological, and nutritional to the psychological, physical educational, and medical The problem is further complicated by the diversity of technical language found in this literature Serious students of the subject are confronted with a truly formidable problem if they address themselves to the task of achieving a reasonable grasp of the entire research field associated with exercise and sports

This symposium, *Science and Medicine of Exercise and Sports*, represents an effort to facilitate the achievement of such a grasp—as well as to outline the frontiers of knowledge in the individual research areas dealt with Accordingly it is composed of a series of authoritative statements as to the current status of knowledge in the major research areas associated with exercise and sports

The following statement was among those sent to each contributor for orientation purposes It is presented here to suggest the intent and spirit which guided the preparation of the book

Purpose of the Book May I emphasize that this book is not intended to be a work in praise of exercise and sports Rather its purpose is to provide an analysis of the status of knowledge related to exercise and sports It should help serious students to acquire a more effective grasp of the extremely diversified research activity which bears upon these subjects It should guide professional workers at all levels in their efforts to make an honest statement as to the effects of exercise and sports upon the human organism It should help researchers in the various areas to know more about "what is going on in the lab next door" And it should serve as a starting point for further research by indicating the frontier of knowledge, suggesting needed research and providing a useful bibliography

All of the contributors were very sensitive to the fact that far more research is needed before definitive statements can be made in regard to their topics Indeed, two intended chapters—physical performance from the perspectives of the geneticist and the psychoanalist—are rather conspicuously

missing from this book because of the editor's inability to locate specialists who believed the available data adequate to support a worthwhile statement

Physical education has to do with the study of the human body in motion Like the field of medicine, it reaches into many fields for much of the data upon which it bases its practices As they pursue their own primary interests, investigators in fields other than physical education frequently make discoveries that are of value to the study of the body in motion, and therefore physical educators are vitally concerned not only with their own research but with synthesizing all pertinent findings from whatever source to form the structure of their discipline It is hoped that the present symposium will assist in this effort to synthesize, serve as a valuable source of information to all interested in exercise and sports, and stimulate future research

The following individuals were of invaluable assistance in the production of this book Lucien Brouha, Elsworth R Buskirk, and David B Dill In addition, Emma McCloy Layman, Granville B Johnson, Jr, Eleanor Metheny, Celeste Ulrich, Lester M Fraley, and Richard Hendricks were especially helpful

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WARREN R JOHNSON

1 ELEANOR METHENY

Introduction The Spiral of Human Knowledge

Scientific truth is not a copy of an image passively received but the fruit of a laborious and endless dialogue between thought and reality [1] At any moment of history man s practices reflect what he believes to be true at that time but the extent to which his beliefs are in accord with the realities of fact is dependent upon the acuity of his powers of observation, his ability to perceive relationships and his capacity for devising theories which account for these relationships His theories grow out of his observations, and each theory he formulates tends to make his observations more acute by establishing a perspective within which they may be more sharply focused, thus enabling him to ask more pointed questions which will in turn elicit more precise information to be used in testing the theory As a result of this circular process he may modify his theories which will then modify his beliefs and practices This motivates the next phase of the endless dialogue and so the spiral of human knowledge about any area of man s life rises in ever

ern science primitive man fashioned his observations into crude theories that guided his practices Some of these theories have been discarded but many of them contained the seeds from which contemporary theories have flowered For example the genesis of William Harvey s proof of the circulation of blood can be found in the primitive observation of a relationship between running and the pounding beat of the heart Morpurgo drew on theories tested by many generations of men who lifted heavy stones to increase their strength when he enunciated his theory of muscle hypertrophy

[1] Albert Dondeyne "Truth and Freedom A Philosophical Study in Louis de Raeymaeker *et al* *Truth and Freedom* Pittsburgh Duquesne University Press 1954 p 37

The ritual war dances of untutored tribes helped formulate the crucial questions Walter Cannon eventually asked about the functioning of the adrenal cortex, and Hans Selye's theory of stress was anticipated by the witch doctors of antiquity

Within recorded history, landmarks on the rising spiral of knowledge about neuromuscular function may be identified in the fourth century B C, when Aristotle noted the phenomenon of reflex action, and in the seventeenth century when Descartes described the relationship between contraction and relaxation in paired muscles, 250 years before Sherrington proposed the theory of reciprocal innervation and validated it in his laboratory In the realm of therapeutic exercise, many of today's theories have their origin in Galen's second-century *Exercises with the Small Ball*, and a host of divergent nineteenth century theories that led to the development of what is now called physical education rested on the careful observations recorded by Hieronymous Mercurialis in *De Arte Gymnastica*, published in 1569 Similarly, in our own time, every exercise theorist must acknowledge some debt to A V Hill, whose *Muscular Movement in Man*, published in 1927, established a new perspective within which the effects of exercise might be studied

In tracing the spiral of scientific development, however, the role of the practitioner must not be overlooked, for it is he who decides the eventual fate of all theories No theory can survive if it fails to meet the test of facts derived from putting it into practice in 'real life' situations, and so in the area of human performance the fate of theories is determined by performers and by the teachers and coaches who guide them It is they who ask the pragmatic question 'Is this theory substantiated by the facts as observed in this specific situation?' If the observed facts are not in accord with the theory derived from the more limited facts of laboratory experiment, the theory will be discarded, but the observed facts will provide a new basis for investigation which may enable the scientists to refine their theories Thus the experience of the practitioner of exercise and sports becomes the second voice in the dialogue out of which the spiral of knowledge rises

As the dialogue between theory and fact has gone on through the centuries, man's understanding of his own nature and the factors that affect his own well being and physical performance has greatly increased Today's [illegible]

thing the tribe knew in order to survive Today more is known about man's nature than any one man can possibly know To be fully informed about even a very small subdivision of human knowledge requires a lifetime of study which precludes intensive investigation in other relevant areas of thought This dilemma can be resolved only if specialists will assist each other from time to time by providing brief syntheses of the current status of

theory and fact in their own fields of intellectual competence This present volume is evidence of the spirit of cooperation which exists among scientists and of their willingness to share the theories which are relevant to the fields of the practitioners

These syntheses of the current status of knowledge in specific aspects of science and medicine that are related to sports and exercise are written not only for research workers, but also for teachers, coaches, and performers As the practitioners of exercise and sports test current theories against the reality of the gymnasium, the running track, and the playing field, they will repay their debt to the scientists by providing them with more sharply focused *observations of fact as seen within these present-day perspectives, to* be used in modifying the theories of future scientists Thus reality will an

PART I

Structural and Mechanical Aspects of Exercise and Sports

2 ALFRED W. HUBBARD

Homokinetics: Muscular Function in Human Movement[1]

SUMMARY

Human movement is the output of a complex, interrelated action system which has diverse potentialities and limitations Human movement has many facets in terms of varieties of performance and research approaches, it has been studied from a theoretical and practical viewpoint by physicists, physiologists, psychologists, teachers, and coaches since movement in some form or other is man's primary mode of performing, accomplishing, and effecting interchange with his environment Macroscopic viewpoints have generally led to superficial treatment, and microscopic analyses, preoccupied with parts, have often led to the whole appearing more synthetic than synthesized The present chapter attempts to provide a simple, theoretical framework of reference into which the manifold and often conflicting research reports will fit, thus it provides a unified basis for understanding skilled human output and motor performance

The active phase in muscle is specifically a tendency *to shorten the origin insertion distance under neural control The alternative is relaxation, accompanied by oxidative restoration of potential energy But muscle length, and more especially changing length, alters appreciably the external, utilizable component of internal muscular tension The inherent relations are such that the muscle initiating segmental movement renders progressively more unfavorable the conditions for external application of its internal tension Skill, or effective utilization of muscular force within the inherent limitations of such a system, is difficult to acquire and even more difficult to explain briefly*

The agonist shortens itself somewhat in initiating a stroke but the segment, having mass and being free to move, has momentum and when set in motion has kinetic energy so that it continues in motion until acted on by

[1] The author is indebted to L D Hartson and Pauline Hodgson for a critical review of this chapter

an outside force (an external object, gravity, or a muscle with opposite action) Consequently, the muscle normally starts the segment and lets the segment continue in motion by its own momentum Or else the muscle tends to produce an impulse (some force for some duration) rather than to pull the segment along behind it as it shortens Muscles are placed anatomically to oppose each other's action yet they need not oppose each other's action directly—one pulling and the other snubbing Such mutual resistance wastes energy and is fatiguing and abnormal since tense stasis tends to result So, in general even in slow movements the muscles tend to act with independent, alternate, discrete bursts of activity of low intensity and of about 50 milliseconds duration with the agonist accelerating the segment slightly, then the antagonist decelerating it slightly, and the process continuing with occasional momentum phases in between Thus, in both slow and fast movements the normal basis seems to be essentially impulse action to generate and degenerate kinetic energy in segments, rather than pulling and snubbing

The muscle essentially a viscous mass, inherently resists a rapid change of shape If the agonist continues to develop tension (as in the laboratory isotonic condition), the internal, 'viscous resistance increases exponentially and soon equals the maximal muscular force, leaving the muscle no residual, external force for accelerating the segment The segment can continue to move by its own momentum but the muscle cannot shorten itself as rapidly as the segmental movement shortens its origin insertion distance, so the segment outruns the muscle Consequently, rapid skilled movements are initiated by a ballistic impulse, or thrown, and the kinetic energy of the segment does the work Under certain circumstances this initial impulse stops abruptly—either to let the segment enter a momentum phase or to avoid ineffective dissipation of tension against internal resistance Control of rapid, skilled movements resides in a correctly directed initial impulse, or combination of impulses The successive parts of slow movements are initiated in the same way—by an impulse in the agonist which ceases Slow movements appear more controlled because the errors are microscopic—and so is productivity But fast and slow movements are produced by the same system in much the same way

Maximal external (utilizable) force in muscle is developed under isometric conditions with some initial stretching Strictly speaking the condition is not isometric if movement occurs and the tension is not utilizable (except for supporting something) unless movement occurs This apparent paradox may be avoided in human movement by having an initial stretching which is approximately equal to the shortening during acceleration so that the condition is essentially, if not exactly, isometric Consequently, where force is important, performers 'wind up,' or in complex movements throw segments into motion to put muscles initiating subsequent action on a stretch For the same reason, much skilled movement tends to be reciprocal since each opposing muscle is thus initially stretched by the stroke it will

decelerate In reciprocal ballistic movements, each agonist acts alternately to decelerate, reverse, and accelerate the segment under conditions which are both essentially isometric and essentially isotonic but, in the latter case, with out the usual connotation of tension dissipation from internal resistance during rapid shortening In general, each agonist acts during about a third of the cycle and relaxes during the other two-thirds Since the limb, once ac celerated, will proceed to the limits of the joint by its own momentum, the amplitude of the stroke is relatively unimportant, but since kinetic energy [illegible]

A major obstacle to acceptance of the general principle of ballistic (im pulse) action as the basis for skilled movements has been the action poten tial evidence of muscle action in tracking problems where the segment is moved quickly to a new fixation In such problems, or in moving a limb quickly and returning it slowly, the original agonist has a dual function After accelerating the stroke, the agonist must shorten itself as rapidly as possible to prevent the ballistic return of the stroke by the decelerating, re versing, and accelerating action of the antagonist In such problems, agonist and antagonist do act simultaneously during the momentum phase of the stroke (if the stroke is of sufficient amplitude for the momentum phase to appear), but they do not act simultaneously on the segment The agonist, having accelerated the stroke, continues to act against its own viscous resist ance in order to shorten itself but exerts no external force to accelerate the segment, the antagonist acts simultaneously to decelerate the segment Since the intensity and duration of the antagonistic impulse rarely balances ex actly the kinetic energy of the segment, the original agonist must shorten itself in order to act in the shortened condition and fixate the segment Tracking problems generally involve strokes of short amplitude and high speed so the initial acceleration tends to merge into the deceleration, and the momentum phase, characteristic of ballistic strokes of greater amplitude, tends to disappear

The human neuromuscular system has numerous lags and limitations but within these, extreme effectiveness is possible Since movement is the es sence of overt behavior, an understanding of human movement is basic to an understanding of normal and abnormal behavior, or superior and in ferior skill The multitude of experimental facts and artifacts in the me chanics, physiology, and psychology of human movement make this difficult without some inclusive and relatively simple framework of reference

MAN—A REACTING ORGANISM

The apparent multiplicity of responses in living organisms can be reduced ultimately to two basic forms movement and secretion Various organs and tissues apprise organisms of events in themselves and their surroundings

(sensory), transport blood and restore energy (cardiorespiratory and alimentary), support and protect (skeletal), and conduct and transmit (neural) Without minimizing their separate and collective importance, these various organs and tissues may be considered as supporting, subserving, and maintaining the basic response systems The basic response systems, in turn, act on and react with the environment In this interchange of action, the glands react to changes in the external environment but, in general, secrete into the blood stream or alimentary canal and so change the internal environment or aid alimentation By changing the internal environment, glands affect indirectly the interchange of action with the external environment But the primary interchange with the external environment depends on motion or muscular action in some form In other words, living, adapting, and effecting changes in the external environment for any purpose depend ultimately on movement and the neuromuscular system Fundamentally, from a functional viewpoint man is movement

Of course, stating that man is movement does not imply that man is nothing but movement, nor that muscle is all important In viewing man's amazing diversity of accomplishments and in attempting to name, classify, and ascribe underlying reasons for them, we must realize that without movement man would be a vegetable, but with it he may only be a higher level animal Not only performances which are obviously predominantly muscular, but all other human production and communication consist fundamentally of motor activity Perception and understanding of the world around us also depend, in part on our ability to move Even memory, thinking, and concept formation may well depend on subovert movements of speaking and writing

If the statement 'man is movement seems far fetched, it is equally un

(senses) and effectors (muscles), and hence must be in the central nervous system or the brain Is thinking this simple? We know something goes in gets filtered and muddled up with things already in and eventually comes out, or gets lost But what is involved in the filtering and muddling up? The brain is a complex of nerve tissue, a complex of connections The primary function of nerve tissue is to conduct and transmit to pick up, convey, and deliver impulses through the body Some impulses are picked up and delivered inside the nervous system because of its structure, but it is little more than a convenient evasion to assume that thinking is completed entirely within the nervous system This is no more logical than to assume that action results from muscular activity alone We know that thinking elevates metabolism and that sometimes we can see evidence of ' thought processes' in operation—the subovert becomes overt Consequently, a process involving sensor neural muscle (with subovert action) sensor neural and eventually overt motor processes is as logical as one assuming sensor

neural neural neural motor processes The intervening processes in thinking could involve primarily subovert muscle action affecting sensors as well as wholly neural action, so the muscles may have more to do with thinking than is usually supposed At least, if we seek to understand complex human behavior in terms of organs and functions, we must eventually concern ourselves with the basic common component—muscles and their action, or movement

Man's interest in himself and his surroundings is age old, but with the machine and the more recent electronic age, research has proceeded at an accelerated rate partly through great strides in instrumentation, but also by greater specialization and compartmentalization These have led to a rapid proliferation of facts and also to progressively more limited integration because of specialization and compartmentalization Research in any area proceeds primarily by finer and finer differentiation, but knowledge and understanding depend on integration and interpretation More refined differentiation has led to more refined integration, but the fact that integration is limited to the terms used in differentiation is axiomatic So greater specialization and compartmentalization of knowledge has led to greater limitations on integration, or to what are partial integrations within areas of specialization rather than complete integrations Integrations of man from the myopic viewpoint of specialized areas often leave one feeling as one does after leaving a hall of mirrors—the parts of man are subjected to various interesting and stimulating exaggerations, but the result is not man

Between area integration is needed periodically to bring specialized research into a broader perspective and, if possible, to restore a better frame work of reference for considering new findings in various areas Human movement needs a framework of reference Competitive athletics, along with skilled performance in any area, provides a basis for testing various concepts at one extreme Apart from structural abnormalities, the functional abnormalities of disturbances of posture, movement, and emotional expression must be explainable at the other extreme Between the two extremes, we have the development of efficiency, the improvement in performance, and the learning of productive and forgetting of unproductive responses which undeniably occur The abnormals are more interesting than the normals The supernormals, in general, can take care of themselves, but the subnormals are the concern of medical and psychiatric doctors and of physiology and psychology—so we know more about idiots than geniuses However, a suitable framework of reference for human movement is a large order which can only be filled here in principle The details may be found elsewhere Since movement is basically physical, we start with physics

Physics

Physical concepts dealing with matter and energy have three basic variables—mass, space, and time Matter, which occupies space, and energy,

which is capable of doing work, may interact and be transformed but neither can be created or destroyed In other words, the interactions and transformations balance and are explainable Bodies have mass (M), velocity (v), momentum (Mv), and a state of motion, or if v is zero, immobility The property of bodies to continue at rest or in motion is inertia, and that which alters this state is a force According to Newton s first law of motion, bodies remain in a state of rest or motion unless acted on by an outside force The second law establishes a balance between the effective force and the change of motion by stating that force equals mass times acceleration ($F = Ma$) The third law states that every action has an equal and opposite reaction which balances or conserves the energy of the system The principles of Newtonian mechanics have been superseded in some ways, but they still provide a basic approach to understanding the mechanics of human movement

Doing work involves displacing a body, and work equals force times displacement ($W = Fs$ where s is space or displacement) Displacing a body rapidly requires power, the time rate of doing work (Fs/t, where t is time, or Fv, where v is s/t) Doing work requires a transfer of energy, and since energy is conserved, the gain of kinetic energy in one body and the loss in the other equals $MV^2/2$ This comes from $W = Fs$, Newton's second law ($F = Ma$), and the fact that if a body starts from rest, $s = at^2/2$ To avoid further complications, note that momentum equals Mv, force equals Ma, and kinetic energy equals $Mv^2/2$ So if mass (M) is constant, momentum is proportional to velocity force is proportional to acceleration (or deceleration), and kinetic energy is proportional to half the velocity squared Or, *if* mass and other physical relationships can be considered essentially constant, we can interpret motion in terms of velocity and velocity changes

How should we consider human motion, in terms of this *if*? Human beings are anatomically homogeneous and heterogeneous The masses and moments differ appreciably in different bodily parts and they differ appreciably between individuals Where mass and anatomical relations differ considerably, they must be considered But in an individual, or in a group of like individuals, the mass, leverage system, and moments of inertia are essentially constant, and hence irrelevant in comparisons Within limits, people are more like than unlike anatomically, and also probably in the principles underlying their movement Consequently within limits, human movement may be considered from a quasi mechanical viewpoint, as if it depended on velocity and velocity changes This approach simplifies understanding muscle action in movement because it focuses attention on the primary function of muscle—its ability to overcome inertia and produce velocity changes in segments by acting as an 'outside force'

Gravity acts in human performance as a force continually accelerating the body and its parts downward and as a resistance against which we must expend energy in maintaining a position or raising ourselves Gravity is also a simple force with essentially uniform acceleration (g 32 2 feet/sec^2) which

physicists commonly use in work, power, and energy formulas In considering work against gravity, displacement (s) is taken as vertical displacement and g is substituted for a in $at^2/2$ However, thinking of work as *entirely* work against gravity leads to an interesting paradox in human performance Thus, if we climb a mountain and return, or break a track record on the flat, we have worked hard to do no *work against gravity simply* because we eventually gained no elevation In these terms, we are everlastingly dissipating our energy and using our power with zero efficiency This seemingly sterile conclusion results from having assumed that s is vertical displacement and so g equals a, and then trying to explain human performance in terms of work against gravity alone We might say that human beings have other ways of "gaining elevation'

If the mountain climber returns to the same elevation and the runner does *no work against gravity, where does the energy go, or how do we explain its* conservation? Each converts potential (muscular) energy into kinetic energy, the energy of moving limbs by which he moves On each stride, muscle action has to degenerate the kinetic energy and regenerate it in reverse Since kinetic energy is exponential, a linear increase in speed requires an exponential increase in energy expenditure The fact that no work was done against gravity indicates that we should look elsewhere to explain its expenditure, not that no work was done Work against gravity is a factor *but often an unimportant factor, in human work*

Anatomy

The anatomical complexities of even the neuromuscular system lead to a maze of intriguing intricacies unless reduced to a simple action system Anatomy is never this simple but, in essence, the system consists of two bones with a joint between, one muscle to flex and another to extend the joint, and a motor nerve serving each muscle The bones serve as supports and *levers Bones and their surrounding tissues make up segments* with mass and inertia Hence, the segments tend to continue in a state of rest or motion until acted on by an outside force Unless the segment delivers or receives a blow from outside, human movement is the result of the interaction of two types of forces, namely the external, constant accelerating force of gravity and the internal, controllable forces from muscles or muscle groups The muscle is essentially an enclosed viscous mass with contractile properties In the absence of neural stimulation, the muscle tends to assume resting length (relaxes) Under neural stimulation, the muscle tends to harden, bulge, and shorten (contracts), but if shortening proceeds rapidly, internal (viscous) resistance develops The tendency to shorten exerts force between the origin and insertion *of the muscle, and this is the internal,* controllable force in human movement The whole system is controlled by nerve fibers which can only act or not act, transmit, or fail to transmit impulses

A misconception concerning muscle action arises from the diametrical arrangement of muscles about joints Muscles are arranged to oppose the action of other muscles so the limb may be moved in either direction, or in several directions depending on the type of joint and the muscle arrangement Counteracting muscles *may* oppose each other s action directly The assumption that they *must* is gratuitous Moreover, the muscle tension on both sides of a joint can increase to a maximum without moving the limb ap

exceeds the other

Such self induced catalepsy will increase strength but it wastes energy and provides a poor basis for explaining all movement Motion *may* be produced by an imbalance of muscular forces since any slight difference in favor of one muscle will produce acceleration The absolute force in the agonist (driving muscle) and antagonist (counteracting muscle) may increase from

a force equal to the difference if the antagonist simply relaxed The basic function of muscles is to overcome the inertia of the limbs and produce fast strokes except that some action is necessary to prevent collapsing Energy expenditure to act directly against or counteract the action of an antagonist is wasted although muscle action to resist the reaction of other muscular action and fixate joints to produce a desired action is necessary The ' self induced catalepsy concept is particularly diabolical because it arises from the perfectly obvious anatomical arrangement of muscles and because it is a hidden assumption impossible to exorcise from much literature

The most common variant of the self induced catalepsy concept is co contraction of antagonistic muscles Muscles having opposing action often act simultaneously In fact, after an extensive review of the research literature, Hill (22 65–66) reported that the majority of research workers found so much evidence of simultaneous cocontraction of antagonistic muscles and so little evidence of ballistic (uniform velocity) strokes that they questioned the existence of the latter in normal human movement The evidence must be accepted, but it should be evaluated with respect to the experimental conditions under which it was obtained before judgment is rendered concerning normal muscle action in skilled movements However, muscle action to alter the inertia of segments or, more specifically, to produce sudden massive, externally effective imbalances seems useful Muscle action to counteract the inertia produced by action of other muscles is an anatomical necessity But muscle action to counteract simultaneously and directly the action of other muscles seems wasteful and seems to provide no sound basis for understanding skilled movement

Sherrington's monumental study (40)[2] has been interpreted by many as evidence that simultaneous cocontraction of antagonistic muscles is fundamental to human movement His findings can be accepted, *as far as they apply* to postural reflexes in decerebrate cats If the cat survives, he can stand, move about slowly and blindly, snarl if irritated, and even drink milk if his nose is placed in it He can survive with his reflexes at a low level for a cat, but he is not normal Sherrington showed, among other things, that a sudden push on the cat's paw was resisted quickly and forcefully

Many skiers also act in this way When frictional resistance to the sliding ski increases suddenly, their reflex is to push down—and go end over end because the push further increases the frictional resistance so that the skis stop, but the skiers do not Good skiers do not continue to act like decerebrate cats, they train another set of reflexes Sherrington should not be condemned on the basis of guilt by association but, although he advanced our understanding of spinal reflex action, others have taken this as the basis for a theory of skilled movement because it meshes neatly with the idea of simultaneous cocontraction of antagonistic muscles and seems to preserve the balance of the neuromuscular system Thus, it ties in with Cannon's concept of homeostasis However, the neuromuscular system produces its external effects by sudden, massive, effective imbalances—and leaves the rest of the system to restore the balance Consequently, the postural reflexes of the decerebrate cat seem to be a poor analogy for generalizing about skilled human performance

A prevalent and convenient misconception of action in the neuromuscular movement system, usually bound up with cocontraction of antagonistic muscles and reflex action, is that the parts of the system act simultaneously, or in phase While recognizing the underlying causal relation between nerve, muscle, and segmental movement, the apparent togetherness has led many authors (for example, 11,16,19,49) to interpret human movement *as though* events in the motor nerve and muscle were in phase or occurred simultaneously with events in the movement cycle The in phase assumption is convenient because *if* nerve action, muscle action, and limb action were in phase, then events in the nerve and muscle action cycle could be inferred from events in the movement cycle The logical basis for the "in phase" assumption (with valid parts italicized) is that *the nerves control the muscles, the flexor muscle flexes the* joint by shortening itself (and the extensor lets it extend), and *as the joint flexes, the origin and insertion of the flexor approach each other (and vice versa)*, so as the joint flexes the flexor must be *contracting* and *extensor relaxing, and the motor nerves must be providing* appropriately graded stimulation The portion of this assumption that makes the conclusion *non sequitur* is hard to spot because it is a half truth The acting muscle *tends* to shorten itself and in initiating movement does

[2] Parenthetical numbers refer to the bibliographical information given at the ends of chapters

shorten itself somewhat But if appreciable acceleration is produced, the momentum of the segment will continue the flexion and the muscle cannot shorten itself as fast as the limb can move (the evidence will be presented later) Efficient muscle action requires that the agonist initiate the stroke under the most favorable conditions and that the antagonist remain relaxed until it must act to degenerate the kinetic energy of the limb before movement strains the joint (unless we want to expend energy on something or somebody) The fallacy of the in phase assumption in fast movements has been pointed out several times but its convenience will perpetuate it (chronologically 23,106–108,29 18 24,42 26,43)

Anatomical relations were reduced rather summarily at the beginning of this section to a simple action system stressing basic functional relationships Then focus shifted to various misconceptions which were related in one way and another to an assumption stemming from anatomical relations Functionally, the human movement system involves two cycles (using cycles to mean a series of events that are repeated regularly or irregularly), a nerve muscle cycle and a segmental movement cycle (with sensory feedback) The events in the nerve muscle cycle are the initiation and cessation of muscle action under neural control and this part of the system is primarily physiological The events in the movement cycle are flexion and extension, except that no motion or fixation may occur at any point in the cycle This part of the system is primarily physical mechanical

The two parts of the system are both independent and interdependent The normal order of events or actions is nerve muscle, bone, and movement The active phase of the nerve muscle cycle provides the internal, controllable force to generate and degenerate kinetic energy in the segment, but the limb can move without muscle action, and the muscle may be active without the limb moving Gravity will generate kinetic energy in the segment and kinetic energy may be degenerated by reaching the limit of the joint or an outside object (either may have disagreeable results) Each element also acts back on the others Muscle action and joint movement produce sensory stimuli Movement changes the relations at the joint This changes of angle of insertion and more especially, the origin insertion distance of the muscle Changing the angle of insertion alters the effective force of the muscle and changing the origin insertion distance alters the conditions under which the muscle develops tension Rapid shortening may dissipate the entire muscular tension and leave no external force available—provided tension is being developed during rapid shortening Moreover, the system operates at a wide variety of rates with some inherent lags and limitations which we learn to accept Consequently, to generalize about the relations of events occurring at one rate to all rates and especially to assume that they remain in phase, seems extremely hazardous The alternative is to determine experimentally the functional activity of muscles in human

movement at various rates, or simply how muscles do act in human movement

MUSCULAR MOVEMENT

Contraction Relaxation

The primary event or active phase in the muscle cycle is a period of tension development during which the muscle hardens, bulges, and tends to shorten This is commonly called *contraction*, which means literally a shortening, drawing together, or withdrawing The counterpart is relaxation, the reloosening, or cessation of tension development The terms are useful in describing muscle action as long as, and only as long as contraction is used to signify a period of tension development, and relaxation a period of tension cessation When contraction implies actual shortening and relaxation implies lengthening of the muscle the in phase assumption is indicated To avoid confusion, the active phase of the muscle cycle is better described as the period of tension development, or as the tendency to shorten This distinguishes events in the muscle cycle from events in the movement cycle

Where reference to the changing length of the muscle during tension development has been necessary, the term contraction has often been used (with the 'in phase assumption) to mean tension with shortening and the contrasting condition has been called a lengthening contraction From a semantic viewpoint, the latter is contradictory, although the meaning is clear To avoid the contradiction, the terms *concentric* and *eccentric contraction* have been substituted to mean *acting with* and *acting against the movement* Since these adjectives actually mean *with the same center* and *off center*, or *erratic*, more accurately descriptive adjectives would be *miometric* (lessening length) and *pliometric* (more length) These with *isometric*, cover the possibilities

Levels of Contraction

The absolute value of muscle tension may vary from zero to some maximum, although the intact muscle probably rarely, if ever, reaches either limit The muscle fiber responds (presumably maximally under the existing conditions) to each nerve impulse that *crosses the myoneural junction* The nerve impulse is of short duration (ca 2 ms) and unless another impulse arrives shortly, the muscle fiber relaxes A series of impulses arriving before their respective relaxations progress very far produces a building up of tension, the "staircase effect If impulses continue to arrive rapidly, tetanus or a tetanic contraction results Anatomically, each motor nerve fiber serves from one to many muscle fibers (Sherrington's 'motor unit') The level of contraction depends on the frequency/nerve fiber, the number of nerve

fibers (and perhaps which fibers) and the duration of excitation or on the density and duration of neural stimulation Myogenic contraction is also possible as the result of a blow

Isolated tension development in one or a few muscle fibers is a twitch and random firing of muscle fibers produces fibrillation Ordinarily neither produces movement and they are considered abnormalities However if the muscle fiber or a small group served by one nerve fiber were in tetanic contraction or if all muscle fibers were to respond simultaneously to one nerve impulse the contraction would probably not move the limb because in one case the density and in the other the duration of muscle action would be insufficient In recordings of muscle action potential many investigators find twitches—action potentials of fair magnitude but short duration—or rather low level but fairly continuous action (which may be simply noise in the amplifiers) These are often interpreted as evidence of action in the muscle even though the limb shows no corresponding evidence of acceleration or deceleration Evidence of even very low level action in the antagonist is also often taken as evidence of cocontraction The absolute magnitude of muscle action to produce minimal acceleration or something like the rheobase in nerves is impossible to determine in situ or at least would be extremely difficult However Stetson and Bouman reported that muscle action potentials with durations of about 45 to 50 ms were sufficient to drive the limb through its excursion and called this the motor unit —a functional rather than an anatomical unit (45 209)

Isotonic Isometric

In the nineteenth century physiologists studied the contractile properties of excised muscle with a lever and kymograph as is done in beginning laboratory courses today The muscle was stimulated with a *uniform electric* shock to produce an isotonic (same tonus or tension) contraction as it shortened in lifting weights Even with reasonably well standardized conditions interpretation of the evidence was rather confused until Fick (*14*) suggested in 1871 that the isometric (same length) condition should be used as a laboratory control Under isometric conditions the muscle restrained from shortening exerted its full force on the recording instrument By comparison the muscle lost exponentially more tension as the speed of shortening increased under isotonic conditions *Since* the muscle restrained from shortening moved no weight and thus did no work physiologists have considered tension development under isometric conditions as of little functional importance in human movement By etymological evolution isotonic has lost its meaning of same tension and has become identified *with tension* development during shortening which is considered the effective work producing active contraction phase of muscle activity in human movement

For many years physiologists interpreted human movement in terms of the

laboratory muscle preparation in which the muscle started from rest and did work with an isotonic contraction, or more accurately under miometric conditions When consideration of pliometric and isometric conditions became an obvious necessity, Fenn (13) suggested three categories of tension in the following order tension during shortening, isometric tension, and tension during lengthening The isotonic contraction, tension during shortening, was placed first because of its (supposed) paramount importance Fenn's schema was used by Lloyd (34) in discussing functional activity of muscles The order of shortening same lengthening is the exact reverse of the functional order where, to put it in simple terms, the windup precedes the pitch and is used to put the muscles under a stretch as they develop tension The necessity of "winding up" has been fundamental in athletic performance for years As far back as 1920–1921, Doi (5) showed that maximal tension occurred not under isometric conditions at the muscle s normal resting length, but under initial extension of from 1 2 to 1 3 times the resting length[3]

Morton, in a scholarly and interesting study of walking, put the changing length conditions in their proper order, lengthening same shortening (35, 215) However, he synthesized muscle action from joint movement and (primarily) gravitational forces (the 'in phase" assumption) He recognized a period of "muscle tension' under pliometric and isometric conditions, but "muscle contraction" was specifically the "active shortening of muscle (contraction) against external forces (isotonic tension) " Thus, the physiological dogma persists that muscle action for doing work involves shortening and implies isotonic tension development In Morton's study, these assumptions led to no glaring errors since he was dealing with low velocity and primarily antigravity movements, so the objection may seem largely semantic If he had used this approach to high velocity movements, he would have run into the problem of muscle viscosity

Viscosity

attributed this to internal resistances which in combination acted like viscous resistance (liquid resistance to a change of shape) Muscle viscosity has been used as a hypothetical reason for differences in running ability (greater viscosity supposedly going with slower running) Muscle viscosity *in situ* is rather hard to measure, so no one has tested this hypothesis However, Hill (20) developed an inertia wheel for measuring muscle viscosity

[3] Ramsey and Street (*J cell & comp physiol*, 1940, 15,11–34) contradict this in

in situ, and the viscosity factor for intact muscle has been recalculated sev
to runners at Cornell and
ised to overcome the fric
e 'viscosity' of the muscles
themselves' Hill went on to say that the exponential increase in energy cost with speed was due to the kinetic energy of the arms and legs which had to be generated and degenerated Actually, his viscosity factor more than explained the energy used

Fenn objected on the basis that in running not all of the energy could be expended in overcoming viscosity and in a series of studies (11,12,13) tried to set matters right He restudied Hill's viscosity factor for intact muscle (13) and arrived at a factor that was about 40 percent of Hill's But even with this, he found that at its maximum speed of shortening in sprint running the rectus femoris lost 112 percent and the biceps femoris 115 percent of its tension as a result of viscosity (12) These rather bizarre findings resulted from the assumption that the muscles were attempting to exert force during the maximum rate of origin insertion shortening Both authors accepted the "in phase assumption Fenn's conclusions would be acceptable provided they were stated in the following form If the muscles which were presumably acting to draw the limb along with isotonic contractions were acting the force necessary to overcome their own viscous resistance would have exceeded by 12 to 15 (and in some cases more) percent the maximum force of which the muscle was capable' The paradox arose from an unrecognized assumption

Evidence that the driving muscles in human locomotion were *not* acting in phase with the movement was found by Hubbard before 1936 (23) and published in 1938 (29) This was later corroborated by Elftmann (8 9) who showed by a complicated mathematical physical analysis that the forces producing the velocity changes in the lower limbs occurred during the change of direction of the movement cycle In other words, both authors showed by different methods that the muscular forces acted at the end, reversal, and beginning of the strokes and dropped out during the stroke, rather than acting throughout the stroke as Fenn and others have assumed

CONTRACTION BALLISTIQUE

Although most physiologists have *persistently perpetuated the 'in phase"* assumption, Beaunis (2) provided a vital key back in 1885 when he reported his research on simultaneous contraction of antagonistic muscles He found that sometimes the agonist drew the limb along against the resistance of the antagonist, but he also found in fast strokes what he called a *"contraction ballistique* This type of contraction impelled the limb, or acted as an impulse (Ft, some force for some time) The limb, once accelerated by the impulse, continued by its own momentum, and the muscle,

having developed kinetic energy in the limb, relaxed The concept of impulse action was revolutionary in physiology and contrary to the "in phase" assumption Although the idea was perfectly reasonable on physical grounds, it has never been widely accepted

Oddly enough, the first practical test of this new concept was made ten years later in the area of sport by Richer who analyzed a soccer kick (37) Beaunis' idea that muscle action in fast and slow movements differed materially was picked up before 1905 by Athanasiu (1), Rieger (38), and [illegible]

[illegible] strokes In 1923, he published with McDill (46) a classification consisting of fixation, slow movement, and rapid (ballistic) movement Dodge (4) had previously reduced eye movements to five types fixation, moving fixation, saccadic jerks, convergence, and rotation By considering convergence and rotation as essentially fixation or moving fixation, this gives basically fixation, moving fixation, and saccadic jerks—with the last the rapid, ballistic, interfixation movements of the eye Thus the similarity between eye movements and the general classification of all movements by Stetson and McDill becomes obvious

After further experimental work, Stetson published a fourfold classification with Bouman in 1935 (45,200) This classification had two main categories, slow, tense movements and ballistic movements, with two subcategories under each fixation and moving fixation under slow, and loose ballistic and tense ballistic under ballistic The only essential change from the 1923 classification was the addition of "tense ballistic, which was an abnormal form leading to occupational neuroses Thus in essence Stetson reduced Dodge's classification of eye movements to three archetypical normal forms and added a fourth abnormal form to cover all forms of human movement

Fixation was "the tension movement approaching null velocity the movement of holding still," or posture with attendant tremor Moving fixation, "the tension movement," involved cocontraction and an imbalance of forces, as in forging a signature where irregular, jerky movement reveals the minute adjustments in the slow controlled movement The loose *ballistic movement was the skilled movement, the quick, apparently effort*less, smooth, and accurate stroke which is basic in speaking, writing, typing, playing instruments, or playing sports The loose ballistic stroke was characterized by an unopposed burst of activity in the agonist which accelerated the limb and then stopped as the limb swung free by its own momentum The "stiff movement," or tense ballistic was like the loose ballistic in that it was initiated by a sudden, ballistic contraction, but was also like the tension movement in that the limb was essentially fixated With

this "forced tremor," movement cycles could be executed at a slightly higher rate than with loose ballistic movements, but this resulted in excessive fatigue and various occupational neuroses if continued

Stetson approached human movement from a broad theoretical and practical viewpoint He was precise and painstaking so his reports were both inclusive and concise, which did not make for easy reading A much more readable and comprehensive review of research in skilled movement was presented by Hartson in 1939 (18) In 1947, Harris Hill presented another excellent review in which he accepted Stetson's categorization (46) as the best basis for ordering laboratory work on human movement, with two reservations These were first that many able experimenters found no evidence or very doubtful evidence of ballistic movements in their records, and second, that the electrical occurrences connected with muscle contraction remained a controversial matter (22,65-66) Both reservations were valid the first because the majority of experimenters have failed to find ballistic (momentum) strokes for reasons which will be explained later, and the second because experimental determination of the phase relation between movement and muscle action in human movement is extremely complex and difficult

Ballistic Isometric Movement

The suggestion that the superior efficiency of skilled movement might be attributable to utilization of something closely resembling the isometric contraction was first made by Stetson and Bouman (45 210) in referring to the ballistic movement, with its essentially isometric contraction" Shortly after, the efficiency of walking and running was found to depend on ballistic strokes with the driving contractions occurring under essentially isometric conditions (25,29) Another paper presented further evidence that in reciprocal ballistic movements the agonist not only decelerated one stroke and accelerated the next with a single burst of activity and then relaxed to let the limb proceed into a momentum phase which was caught, reversed, and returned by the antagonist, but also that the discrete bursts were of essentially the same magnitude and duration for strokes of the same velocity (24) The magnitude and duration differed for strokes at different rates Thus at least in reciprocal ballistic movement cycles, the muscle force acted as an impulse (Ft) or acted as an essentially uniform external force for some duration Whether the internal tension development could be considered isotonic depended on the conditions of changing muscle length under which the tension was developed and applied

Physiologists generally use 'isometric" in a strict sense which makes it analogous in human movement to fixation, as in supporting a weight motionless, or the instant of null velocity between extension and flexion However, the period of tension development in reciprocal ballistic movements occurs quite symmetrically about the hairpin curve at the end of the stroke

as it degenerates
(miometric) as
ing deceleration
and acceleration is very nearly equal and the lengthening and shortening is slight compared to the amplitude of the stroke Whatever dissipation of internal tension resulted from viscous resistance during shortening and acceleration would be matched by a gain during lengthening and deceleration, so the net loss would be zero and the conditions would be essentially isometric At least, the conditions would approximate more closely the isometric as studied in the laboratory, with approximately full external application of internal tension than the laboratory isotonic condition in which stimulation is continued throughout the full excursion of the movement and external tension is rapidly degraded to zero by internal viscous resistance In other words, reciprocal ballistic movement cycles were produced apparently by isotonic contractions *not in phase* with the movement but under essentially isometric conditions The key to skilled movement is the timing of the period of muscular tension development in the movement cycle so that approximately full utilization of internal tension under essentially isometric conditions is possible

HUMAN MOVEMENT

Cocontraction Versus Ballistic Action

As Hartson pointed out (18,263) two conflicting viewpoints have grown up among analysts of human performance who have sought to explain human movement in terms of physical, physiological, and psychological principles The conflict has been between viewpoints, rather than individuals, with each group largely content to ignore the other The basic difference between the viewpoints lies in whether the nerve muscle cycle and the segmental movement cycle are considered in phase or not necessarily in phase but related In other words, one group has followed the common practice among physiologists of assuming that isotonic contractions cocontraction of antagonistic muscles, and some reflex balance of muscular forces explained all human movement regardless of velocity This group has pretty consistently failed to recognize the significance of the *initial discovery of Beaunis and subsequent work following his lead* The other group, following Beaunis and Richer, has sought experimental evidence of the incidence and duration of muscle action in a wide variety of human movements and have found ballistic strokes present universally in fast, efficient, skilled movement (18,276)

The interpretation of experimental results depends in part on instrumentation, in part on the background and experience of the worker, and in part on the problem Many analysts of human movement are satisfied with

the results or superficial aspects of movement, such as coaches, therapists, and specialists in work psychology or human engineering, who use a pragmatic approach to practical problems Many experimenters have been misled by instrumental artifacts, especially those who have used rather massive lever systems for recording human movement or those who have attempted to discuss muscle action on the basis of cinematographic records Three critical discussions concerning research methodology for recording human movement and muscle action have been published by individuals with research experience The first was by Wendt (50) in 1938, the second by Davis (3) in 1948, and the third appeared a year later (26) Adequate instrumentation depends on two things, namely, a continuous, time displacement curve which reproduces accurately velocity changes in the segment, and a simultaneous record of muscle action, obtained generally in the present day by amplification of muscle action potentials The movement recording system must be as nearly as possible free of mass, friction, and what Davis called back action —distortion of the movement by loading the limb The muscle action potential recording system needs high amplification (1 1 000 000) low noise level flexibility, rather high recording speed, and freedom from instrumental artifacts Adequate recording is extremely exacting and full of hidden hazards Interpretation of records is equally difficult

Before proceeding to the problem of inability to find experimental evidence of ballistic strokes in human movement, a few examples of unrecognized evidence of ballistic action will be presented Peters and Wenborne (36) presented data which they interpreted as evidence of acceleration to the midpoint of the stroke and deceleration to the end Examination shows that during the middle portion of the strokes the limb was traveling at essentially uniform velocity Edgerton and Killian (6) using stroboscopic light in analyzing the golf stroke, found evidence of uniform velocity from about 30° before contact to 30° after, except for a slight drop in velocity of the club head at contact Edgerton made quite a point of the fact that Bobby Jones accelerated the club head to contact, but the slight acceleration from about 30° before to contact was shown by Slater Hammel (41) to be the result of distortion as the club head approached the camera Presumably, Jones also used a ballistic stroke Taylor and Birmingham (47) recorded acceleration and deceleration of the hand in executing tracking movements Most of their results, like most involving tracking showed a rapid acceleration followed by deceleration—and then some adjustment to match pointers at the end of the stroke However, they reported that about 1–2 percent of the records showed acceleration, a short uniform velocity phase, and then deceleration The proportion was so small that it was later interpreted as no evidence of ballistic strokes (15,1321–1322)

Many of the recent studies reviewed by Hill (22) involved tracking which was studied extensively during World War II to determine the human

equation" in antiaircraft fire Quite a number of experimenters recorded the movements by one method or another, and some also recorded muscle action potentials simultaneously Most found little or no evidence of momentum phases in the movements, and the latter found pretty general evidence of cocontraction of antagonistic muscles during the strokes From these studies Hill (22,55–56) concluded quite properly that the inability of many investigators to find evidence of ballistic strokes in human movement and the evidence of cocontraction of antagonistic muscles cast some doubt on the general applicability of the ballistic concept as a fundamental principle in skilled movement

Beside being a vital wartime problem, the tracking problem has certain vital aspects as a human movement problem In essence, the tracking problem requires the subject to match the movement of a target as quickly and accurately as possible The simplest equipment consists of a pointer which can be moved quickly to various positions and a second pointer with which the subject tries to match the movement of the target Target movement may be discrete or continuous, but speed and accuracy in matching is the goal Most such situations involve starting the limb from some resting position, moving it a relatively short distance as rapidly as possible, and then making minor adjustments to refine the match with the target Note especially the two requirements relatively short distance and extreme rapidity in starting and stopping the movement

Impulse Action

Subsequent to Hill s review (22), a study was undertaken to determine whether essential differences existed between slow and fast movements, and the conditions underlying evidence of cocontraction of antagonistic muscles in fast (presumably ballistic) strokes (27) Previous investigators had worked primarily with slow or fast movements, but in this study the transition from slow to fast was investigated by keeping stroke amplitude essentially constant and increasing the cycles per second The purpose was to find a stroke velocity (amplitude/duration) above which slow, tense, moving fixations disappeared and below which simple ballistic strokes (those with a single series of acceleration momentum deceleration phases) disappeared The evidence showed that slow, tense movements disappeared at stroke velocities above about a third to a quarter of the maximum for the segment and below this point simple ballistic strokes tended to disappear The two types seemed distinctly different

However, the experimental evidence also indicated that although slow and fast strokes differed in certain characteristics, the neuromuscular basis of both was essentially similar In slow movements (Fig 2 1 and Fig 2 2) the limb showed a series of accelerations and decelerations, with occasional momentum phases in between, by which the limb proceeded to its destination The muscle action showed intermittent, alternate action in short

bursts A brief, low level burst of activity (of about 45–50 ms duration) in the agonist was coupled with acceleration This was followed rather shortly, but sometimes after a brief momentum phase, by a similar burst of activity in the antagonist which decelerated the segment The agonist acted again and by a series of such actions the segment was moved In other words, cocontraction of antagonistic muscles, which had previously been considered normal in slow, 'tense' movements was not found The evidence indicated that qualitatively slow movements were produced in essentially

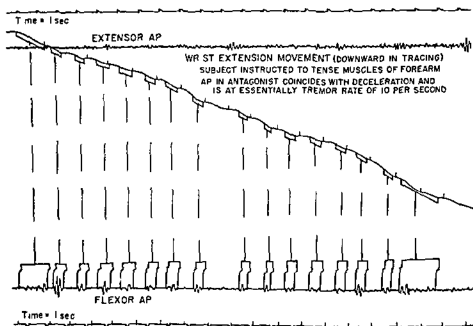


FIG 2 1 *Intermittent deceleration in slow movement*

the same manner as fast strokes That is, essentially by alternate, impulse action exerted against the inertia of the limb and not by simultaneous cocontraction of antagonistic muscles acting against each other across the joint The difference between fast, ballistic strokes and slow, "tense' strokes was a difference in the magnitude and duration of the muscle impulse, but both seem to be effected by discrete impulses rather than continuous contractions of graded intensity

A general concept of alternate impulse action in muscles and nerves seems more acceptable on the basis of the known properties of nerve and muscle than a concept of continuously graded action which would maintain in the agonist and antagonist essentially a constant difference in effective force as differences in length and angle of insertion occurred during movement In these terms, the normal basis for human movement would seem to be discrete bursts of neural activity occurring in alternation

to produce muscular impulses which alternately act independently to accelerate and decelerate the segment The duration, intensity, and combination of these bursts of neural activity and associated muscular impulses result in the wide variety of movements common in human behavior and motor performance This does not preclude the possibility that impulses of essentially equal intensity and duration might occur simultaneously in antagonistic muscles, either intentionally to fixate a joint or inadvertently to upset a movement cycle The general concept of alternate impulse action is

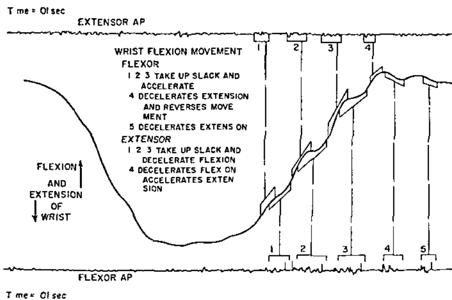


FIG 2 2 *Alternate impulse action in slow movement*

possible in terms of the physical, physiological, and neurological properties of the system, and one system should have a common basic principle of operation

COCONTRACTION IN BALLISTIC STROKES

Figures 2 3 and 2 4 show movement and muscle action in two types of movement problems requiring fast action Figure 2 3 shows simple oscillation with reciprocal ballistic movements in which the acceleration (A), momentum (M), and deceleration (D) phases are indicated The incidence and cessation of flexor and extensor muscle action correspond respectively with the initiation of deceleration and termination of acceleration near each end of the stroke Between acceleration and deceleration the segment travels by its own momentum (equal space in equal time) for a brief duration but considerable excursion Each muscle is stretched somewhat and then shortens itself a corresponding amount, so the condition under

which it develops tension could be considered essentially isometric This is the simple archetype of skilled movement and many similar examples have been published previously

Figure 2 4 demonstrates muscle action and movement where the problem was to accelerate the limb rapidly from a resting position and then return it slowly to the initial resting position The interpretation of muscle action is on the figure, but start with Flexor AP (action potential) 1" which generates kinetic energy for ballistic flexion After a brief cessation of

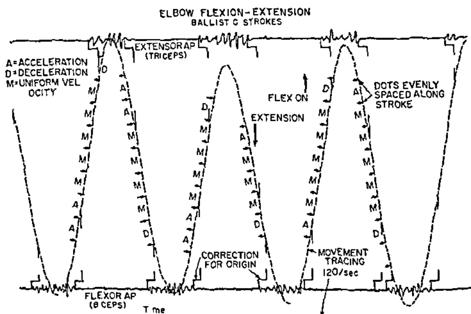


FIG 2 3 *Reciprocal ballistic movement*

action, Flexor AP 2' shows perhaps increased muscle action in the flexor which continues during 'Extensor AP 2,' the decelerating and reversing muscle action, *and also* during a brief momentum phase in extension Note that during 'Flexor AP 2' the intense activity in the muscle produces *no* acceleration in the limb and does not prevent the limb from reversing direction and starting a ballistic extension stroke In other words, during this interval the flexor is exerting no effective force on the limb What is it doing? The problem was to return the limb slowly During ballistic flexion the origin insertion distance of the flexor was decreasing rapidly, so during 'Flexor AP 2 the flexor was shortening itself as rapidly as possible in order to act in the shortened condition to prevent a fast, ballistic extension by the extensor Thus the flexor was exerting its tension against its own viscous resistance and the limb outran the muscle because the muscle, even with probable maximum tension development, could not shorten itself

it back at lower velocity, but with a single ballistic impulse

This evidence of cocontraction in ballistic movements indicates that the agonist does continue its action during action of the antagonist, *but* without exerting force on the limb until it has overcome its own viscous resistance and until the antagonist has started the limb back If the impulse in the

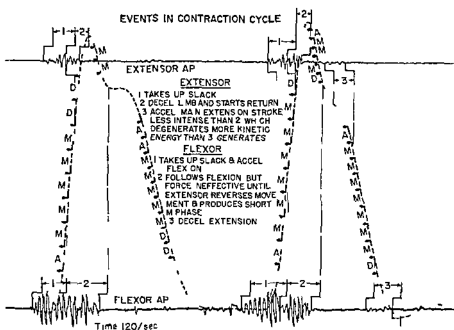


FIG 2 4 *Cocontraction of antagonistic muscles without coincident action*

antagonist were precisely sufficient to degenerate the kinetic energy of the segment, the limb would come to rest in the new position But unless it happens to be, the agonist must struggle along after the limb which has outrun it, fighting its own viscosity, in order to act in the shortened position Any problem which requires the muscle to act and then immediately after to act again in the shortened position to prevent return, or too rapid return, of the limb will produce evidence which looks like *coincident action* of antagonistic muscles in fast movement, but is cocontraction without coincident action Tracking problems, in general, require such action So what is cocontraction and looks like coincident action of antagonistic muscles in fast movements would be normal in this situation The reason that clear cut evidence of momentum strokes was not found in tracking problems was that maximum speed was required and insufficient amplitude

was allowed for the momentum phase to appear more than momentarily, if at all

The resultant action by the organism is a compromise between the problem put to the organism and the capabilities of the neuromuscular system available to the organism for solving the problem The muscle normally acts against the inertia of the limb When the problem demands it, the muscle may have to act against its own viscosity The muscle may also act against gravity, blows from the outside, or directly against the force of an antagonist Frictional resistance in the joint and surrounding tissue may be present, but until it has been demonstrated that frictional resistance is an appreciable force in human movement, it can be disregarded Inertia, viscosity, gravity, blows and other outside forces and antagonist action are the resistances against which the muscle acts Any assumption that the muscle *always* acts against any one of these resistances is purely gratuitous, like the assumption that the nerve muscle cycle and the movement cycle are in phase Consequently adequate analysis of human movement and interpretation of physical, physiological, neurological, and psychological facts concerning the elements of the neuromuscular system in action depend fundamentally on the relation of muscle action to movement and interpretation in terms of the existing condition At this point instrumentation and assumptions become critical

The neuromuscular system is basically in unstable balance, a system maintained loaded and ready for action' and depending ultimately on an on-off control The basic switches may be considered normally open or normally closed If normally open, closing them initiates action If normally closed, they must be held open suppressed, or inhibited until action is desired Consequently the system can be viewed as one in which specific stimuli serve to trigger (close switches for) specific actions or as one in which stimuli create a minor explosion of activity until suppression, except for action toward desired ends is restored Either view may be taken as a basis for learning or acquiring adaptive behavior Adapted behavior is the right answer which depends on the problem and the accepted solution The development of adaptive behavior may be viewed as a process by which the organism closes the right switches at the right time, or as one by which the wrong switches are kept from ' popping closed inadvertently and only the right switches are allowed to close at the right time Either way, the live organism is certainly set to pop into action, some of which is especially productive and effective (the normal skilled) and some is ineffective and wasteful (the unskilled and abnormal)

Functional Limits

Obviously, the lower limit of slow movements is fixation, the movement at null velocity, which can be achieved only temporarily because of tremor resulting from minor, unrepressed bursts of activity The neuromuscular

system has an upper limit with an interesting combination of conditions, an interesting result, and interesting implications Most human movement is cyclical and segmental movement is essentially reciprocal So the upper limit of reciprocal ballistic movements in a way typifies the upper limit of the neuromuscular system

In a stroke, starting with the agonist extended and unopposed by the antagonist, maximal action by the agonist produces maximal acceleration Segmental acceleration increases the rate of shortening in the agonist As the rate of shortening increases linearly, the viscous (internal) resistance increases exponentially Thus the duration of application (T) becomes limited as the effective force (F) becomes maximal Even though internal force remains maximal, no accelerating force is available when internal resistance equals internal tension Some limit of the accelerating impulse (Ft) is reached, which limits the velocity of the momentum phase The limb would continue by momentum to the limits of the joint (or to an external object) unless acted on by the antagonist In repetitive (reciprocal) strokes, the segment acts like a piston which is *decelerated*, *reversed*, and accelerated at the end of each stroke by muscular impulses—each limited in [illegible]

force to degenerate and generate the kinetic energy of the segment With F maximum and t limited, a limiting rate is reached—and also maximum momentum in the ballistic phase At this rate flexor and extensor act alternately during about a third of a cycle Each has two thirds of a cycle for relaxation And each momentum phase occupies about a sixth of a cycle Beyond the limiting rate of constant amplitude, the rate of alternation can be increased only at the expense of amplitude, since with F maximum and t limited the decelerating force must enter earlier in the momentum phase Thus, as rate is increased, the end of one muscle impulse and the beginning of the counteracting impulse approach each other in time and we approach a condition of cocontraction of antagonistic muscles with *coincident action* If the rate of alternation is forced to the point of cocontraction with coincident action, the *result is fixation* stasis, or breakdown of the movement cycle Experimental evidence of this may be found in Stetson and Bouman (45 Fig 5 movements 13–15 Fig 11, movement 23–24), Hubbard and Stetson (29, Fig 5), or Hubbard (25 Fig IV)

Paradoxically, the lower limit of slow movements and the upper limit of fast movement is the same (fixation, stasis, or null velocity) and is produced by essentially the same condition, coincident equal action of antagonists (not considering gravity and remembering that equal includes anything from zero to maximum) Fortunately, between these limits we have a wide range of possible action at different rates and different amplitudes The rate of diminishing effectiveness (where Fs decreases because s decreases)

and the absolute upper limit in rate (where Fs becomes zero because s be comes zero) are both a function of the mass and moment of the segment With lower mass and moment, we find higher reciprocal ballistic rates For the extended lower limb, the maximum is about 2 5 per second and for the finger or tongue about 8–10 per second These rates can be increased slightly, but with reduced amplitude, by resorting to "forced tremors' which are extremely fatiguing

The skilled performer keeps reciprocal rate below the rate of diminishing effectiveness and, in general musters forces from other parts of the body to increase the amplitude of the primary strokes while maintaining their rate Occasionally in track, we see a performer attempt to increase his speed by increasing his rate of limb alternation, with the result that he decreases the amplitude per stroke and slows down He also fights harder and straight ens up Conversely the length of stride (amplitude) may be too great so the rate decreases With maximum rate and maximum amplitude each ac complished at the expense of the other, we have to settle for an optimum You rarely see a breakdown (momentary fixation) in track, but 'breaking" is common in sulky racing where horses are limited to trotting and pacing Here the breakdown results not in a fixation, but in a breaking over into a faster gait, the gallop The skilled performer either keeps the rate below the rate of diminishing effectiveness brings more forces to bear, or breaks over into a faster mode of operation (within the limitations of the organism and the problem) by fusing movements (45,236–237)

CONTROL

The slow movement, because of low velocity, does not outrun the agonist so it can be nudged along, slowed down, and accelerated with small, dis crete bursts of activity in the antagonist and agonist, and progressively nudged into a reasonable approximation of the result desired But the result is a slow, laborious, forgery of skilled movement A fast ballistic stroke is beyond immediate muscular control, but this does not mean that it is out of control The control lies in aiming the stroke and providing the right combination of forces to initiate it, like aiming and firing a rifle But like firing a rifle, once appreciable momentum is developed in the limb the limb is gone So all one can do is reload, return the limb, and fire again

The difference between slow 'controlled' movements and fast ballistic movements is not a matter of inherent accuracy since ballistic strokes, as in *shooting a basketball, throwing a ball, or stroking a tennis ball*, can become highly accurate In ballistic strokes, control depends on a proper set or alignment, proper initiation of the action, and then letting it go without interference by antagonists This is commonly called relaxation, meaning loosening up and letting fly," not just relaxing The difference between slow "controlled' movements and fast ballistic movements is primarily a

matter of velocity which limits control of fast movements to the original impetus

COMPLEX CONTROL

High speed, electronic, machine control systems (servomechanisms) are in many ways analogous in principle to neuromuscular control, which also has error sensing and feedback circuits in vision and kinesthesis (39,198–306,15,1316–1335) But as Ruch pointed out, 'The question arises whether the report back from the muscles during voluntary movement occurs with sufficient rapidity to permit effective control through the course of the movement" (39,203) The evidence presently available indicates that the answer is probably 'yes" for slow movements and "no' for fast movements The limit beyond which reasonably close control in terms of small, alternate impulses in the agonist and antagonist breaks down is probably well below the upper limit of slow movements, or roughly at about a sixth to an eighth the maximum velocity of the segment Initial impulse control probably takes over at about the lower limit of ballistic movements Skilled workers with an exaggerated tremor cannot make fine movements slowly, but they can make them rapidly by striking with the tremor The thrown limb is beyond immediate alteration from visual or kinesthetic feedback, which inform us of errors being committed But the stroke is directed and skill depends on this initial direction or misdirection

Ruch (39,198) objects to the concept of a cortically '*performed*' set of orders for complicated tasks partly because this precludes modification during action and partly because sufficient cortical delay and timing circuits are difficult to explain But as Hubbard and Seng (28) pointed out in a study on batting, except for bunting which is a slow movement allowing adjustments, the temporal framework for the swing is determined by ball speed *In this framework there is an instant, varying with ball speed, at which the* foot must be planted and the swing started, and an instant when momentum must be translated to the bat in order for the bat to meet the ball—or miss it When any considerable momentum is developed in the bat, it is beyond further adjustment Many sport skills have an instant beyond which additional sensory information can no longer be used but this does not mean that they are cortically preformed since most skills and tasks have serial stimuli and instants of choice when decision must be made, or the performer is "aced'

Extended and complex patterns of movement may not be explainable on the basis of delay circuits in the cortex without resorting to some hypothetical set of orders, but this is not necessary Movement produces kinesthetic and visual stimuli, probably not in time to correct misdirected fast movements, but in time to make adjustments in succeeding movements, and also in time to set off neuromuscular action in other parts of the body

The gymnast knows and practices his routines, but if something goes wrong he can often save it with a subsequent compensatory movement, or at least collect himself for the fall The typist often senses that a mistake has been made, but rarely in time to prevent it The pianist uses waste motions, shifts in posture, and lower limb movements to time his series and fill in intervals The stimulus which sets off a run need not be stored in some cortical delay circuit It may come from a twist of the body, the foot, or the seat of the pants—and be harder to locate in situ than delay is to explain in cortico

EMOTIONAL BEHAVIOR

Both the Cannon and James Lange theories concerning emotion involve the more primitive, less well understood partly glandular, autonomic nervous system But as Lindsley stated Emotion is one of the most complex phenomena known to psychology Any final description of emotion must be in terms of the reacting organism the scientific study of emotion must be confined to emotional behaviour, broadly interpreted, and to its underlying mechanisms (33 473) Aside from autonomic and overt glandular responses, the neuromuscular system provides at least the overt part of the underlying mechanism for interaction with the external environment in emotional behavior as well as other behavior The conventional viewpoint of emotional behavior as disorganized (unproductive, diffuse, and misdirected, or frozen and tense) was criticized by Leeper (32) who advocated the concept of emotion as motivation on the basis that, if emotion is a continuum, the better way to view it is that increasing emotion produces better organization and more productive performance As he indicated, increasing performance with increasing emotion fits most of the continuum, but a limit is sometimes reached beyond which disorganization and degeneration of response may occur Young (51) countered primarily on the basis that organization was the opposite of disorganization so this was merely a matter of reversing an axis as far as emotional behavior was concerned But this left apathy matched with best performance and organization at the low end of the emotion continuum Briefly, emotion as motivation fits most "normal' behavior better and emotion as disorganization fits 'emotional behavior,' but neither fits the other end of the continuum

The conflict of viewpoints, as far as it concerns behavior, can be resolved in terms of the general principles of human movement We generally increase effectiveness by increasing the rate and/or amplitude of movements to some point of optimum effectiveness, or some best combination of rate and amplitude beyond which either affects the other adversely to produce diminishing returns In other words, emotion as motivation matches increased productivity, organization, and effectiveness *up to* this inflection point Beyond this, increasing emotion produces diminishing effectiveness, and with it probably mounting frustration which drives the organism to

'breakdown"—the fixation of disorganization With an organism super ready to 'fire' from mounting emotion, mounting frustration, and no *adapted outlet, profuse* and misdirected behavior may result The athlete has an emotional build up before contests (31), but the well trained and well-controlled athlete goes into action and stays below the inflection point, rarely going over into diminishing returns just like emotionally con trolled individuals in any other area In fact, a good way to be beaten in sport is to make an opponent *angry*, but a good way to beat him is to make him *mad* However, in terms of human movement, the two viewpoints of emotional behavior are not as antithetical and incompatible as they appear And in sport, the emotion as motivation concept seems to fit better, except that excessive emotional build up with relatively unskilled and untrained individuals often results in poorer performance, although this is often an ex post facto excuse

CONCLUDING REMARKS

About 100 years ago, Fick introduced the isometric condition as a labora tory control so the external tension of muscle acting at fixed length could be compared with that of a muscle free to shorten during tension develop ment Isotonic refers to the tension developed, or more specifically to some level of constant stimulation The length (metric) and tension or stimu lation (tonic) are discrete factors and by holding one constant (iso) the effect of the other could be determined in the laboratory The not free to shorten condition became associated with muscle action to hold a position *and do no work The free to shorten was similar to the working condition in* the intact organism, thus the isotonic contraction was considered the arche type of "normal human movement To insure recording of the whole effect in the laboratory, stimulation was continued beyond the instant when the free to-shorten muscle ceased to exert external tension In other words, long stimulation insured getting the whole effect, but short stimulation mixed tension loss from internal resistance with tension loss from relaxation Aside from gravity, if the limb moved, some muscle must be moving it The error in applying laboratory findings to human movement came from assuming that the free to shorten muscle must be developing tension *throughout* the excursions of the segment—which was not necessary in a segment with mass and momentum

In a brief, obscure report in 1885, Beaunis pointed out that the muscle could throw the limb into motion with an impulse, or '*contraction bal listique*," and then relax as the limb proceeded by its own momentum Richer found that the foot was thrown at the soccer ball, and Dodge found that the eyes were thrown from one fixation point to another by saccadic jerks Subsequently, in this country, Stetson and his co-workers found thrown, or ballistic, strokes in movements as varied as speaking and running

Since "ballistic" refers both to the conditions under which the movement is produced and to the produced movement, confusion between thrown and throwing movements has existed A convenient method of identifying ballistic strokes in laboratory records was by their momentum (uniform velocity) phase Many experimenters have failed to find this momentum phase (for reasons explained above) and were naturally suspicious

The fact that a momentum phase does, or does not, appear is irrelevant [illegible] efficiency of the stroke depends on the conditions attending its pro[illegible] [illegible] momentum at the beginning [illegible] [illegible]icient production, the im[illegible] [illegible] possible and to maintain [illegible] complished by moving the proximal segment ahead of the distal segm[illegible] the agonist develops tension under lengthening (phometric) or same length (isometric) conditions as long as possible Skilled pitching, shot putting, and discus throwing are excellent examples of developing momenta serially to put successive agonists on a stretch The difference between a good discus thrower and a poor one is that the poor one uncoils as he spins across the circle and the good one stays coiled until set to throw Therefore, if you want force, wind up, and if you want accuracy, initiate the stroke properly and let it go

[illegible] momentum (ballistic) phase consider the [illegible] ulting from elongating a sinusoidal curve When they also [illegible] nist and antagonist active during a stroke, they consider cocontraction basic to human movement Cocontraction without coincident action (and fixation) does occur during fast strokes (for reasons and under conditions explained above) Almost anything can happen in a complex organism and the presence or absence of cocontraction, like the presence or absence of ballistic phases depends in part on the problem put to the organism However, assuming that all human movement involves cocontraction of antagonistic muscles, and then trying to explain how a neuromuscular system whose unsolvable problem is mainte[illegible] [illegible] fixation could effect a finely graded transition from ac[illegible] [illegible] of length and [illegible] xtremely difficult, if not unsolvable, problem

Stetson's major distinction between fast (ballistic) and slow (tense) movements produced a tendency to look for differences and at the same time to forget that the te[illegible] developed for fast ballistic strokes was monumental in comparison to t[illegible] [illegible] The "moving fixation" [illegible] incident action, or with one muscle pulling and the other [illegible] sequent evidence suggests, at least, that both slow and fast movements are produced by discrete muscular impulses acting essentially without resistance

from an antagonist to produce momentum and kinetic energy in the segment The difference between slow and fast movements appears to be primarily in the magnitude of the impulse Thus the "normal" basis for human movement seems to be intermittent, impulse action with intervening relaxation, except that under certain circumstances the muscle must follow the segment to act in the shortened condition and also that muscle tension can vary from zero to maximum with no segmental movement if the tension is equal and simultaneous

Many extremely interesting, and in some ways important, facts concerning muscle and muscle action have been omitted Thus the present synthesis may seem incomplete However, the development of human skill depends as much on suppressing unproductive muscle action as it does on developing maximal force in selected muscle groups at the right instant

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Anthropometry in Relation to Physical Performance

SUMMARY

Anthropometry is that branch of anthropology that is concerned with the taking of measurements on the human body This discussion has been confined to the kinds of measurements commonly used in associating physical performance with body build

Linear and circumferential measurements are employed most frequently since they are easily obtained and provide useful information concerning both physical growth and physical development They also provide the basis for many useful indices These indices may serve in differentiating between the performances of individuals when linear and circumferential measurements alone do not provide adequate information Such indices as the ratio of upper leg length to lower leg length, and leg length to trunk length, have shown positive correlations with the performances of track men who run various distances

Indices have been formulated too from linear and circumferential measurements to determine the relative linearity or stockiness of body build The majority of these have been based on height weight relationships, although others, such as the ratio of the chest circumference to height, have also been used

The measurement of the amounts of the various tissues of the body has proved to be a challenging problem Associated with these measurements is the determination of body density By means of improved instruments for measuring skinfolds, it is now possible to determine body density from a selected group of fat measurements It appears from the results of recent researches that the determination of body density provides another useful method for associating body build with performance

Various methods of body typing as a basis for relating structure to performance, have been proposed Not until Sheldon's somatotyping tech

niques were described in 1940, however, was one method widely accepted Numerous studies in sports and medicine have been done in the past two decades in which Sheldon s methods have been used advantageously Although there is more work to be done in this field, it appears that somatotyping is firmly established as a basic factor to be included in structure function studies

Photography has been used extensively for evaluating posture and for body typing, and it has now proved to be of value in taking anthropometric measurements The science of photogrammetry has improved to the point where many measurements formerly taken directly on the body may now be recorded from a photograph This procedure provides better records and reduces the danger of computational errors

Since anthropometric measurements are used by scientists in many areas of research it is desirable that steps be taken toward standardization There is no separate organization comprised of anthropometrists and for this reason it would be desirable that a national association such as the American College of Sports Medicine, sponsor a conference devoted to the achievement of this goal

Anthropometric methods may be used independently in analyses of body build, to make comparisons between populations and for longitudinal studies of the same population These methods too, are useful in relating body structure to both physiological and psychological functions Anthropometry is a comparatively young science and as the techniques of measurement are improved, it will be used in an ever increasing number of research studies

HISTORY

Contributions to applied anthropometry have been made by workers in many fields The most significant contributions have been made by physical anthropologists Lesser contributors include artists anatomists, evolutionists, and physical educators Seaver (41) has presented much of the history of the ancient period relative to anthropometry He has discussed the Egyptian and Greek eras citing the contributions made by the Greek artists and sculptors Hrdlicka (19) has pointed out that the roots of anthropometry reach far back into time, but that the major contributions have come about during the last two centuries These contributions have been made as a result of studies of human races of human remains, and of human growth The reader who is interested in the history of anthropometry is referred to the texts by Seaver and Hrdlicka

PRINCIPLES

Anthropometric measurements, to be of scientific value, must be objective, reliable, and valid Unfortunately, there are major differences of opinion in respect to the techniques to be employed in taking measurements

Summaries of the Monaco and Geneva Conferences, that were held in an effect to standardize the techniques for taking anthropometric measurements, may be found in Hrdlicka's text *Practical Anthropometry* Definitions of the measurements approved by the Congress at Geneva have served as a guide for many studies which have been done since 1912 Many of the definitions, however, are neither complete nor clear and consequently there are variations in the techniques used by different investigators

In view of these variations, it is important that a detailed explanation of the techniques employed should be included in every anthropometric study, otherwise, there is no opportunity to compare the results of one study with those of another

Basic principles to follow in anthropometric studies include (1) the selection of measurements, when possible that are based upon acceptable standards, (2) the standardization of the subject s position, (3) the accurate location of anatomical landmarks (4) the proper application of the instruments used to take measurements, (5) the accurate recording of measurements, (6) the use of the proper statistical method in analyzing the data, and (7) an accurate and comprehensive report of the results of the study

ANATOMICAL LANDMARKS

Landmarks can be easily located on the human skeleton, and for this reason it is best to use skeletons in preference to living subjects when possible There are data that cannot be taken from the skeleton, however, and it is necessary that the degree of error be held to a minimum in the location of anatomical landmarks on the living subject In order that landmarks may be readily and accurately located, many hours of practice on the living subject (after locating the landmarks on a skeleton) are necessary Since the location of landmarks varies from subject to subject, experience with a wide variety of body types is desirable

An excess of subcutaneous tissue and fat reduces the accuracy of the investigator's measurements and, in the overweight subject, it may be impossible to locate a landmark The comparatively few subjects on whom it is not possible to locate bony landmarks should not discourage the anthropometrist from working with living subjects

After determining his self reliability, the investigator may wish to check his reliability against that of another competent anthropometrist This is a 'must' for the inexperienced investigator If there is a question concerning the validity of a given landmark, a comparison should be made with an x ray

Since relatively few landmarks of the head and face are taken for studies in the areas of growth and physical performance, it is left to the reader to seek this information in a text such as Hrdlicka s (19) The landmarks on the body and limbs include the suprasternal notch, the nipple, the umbilicus, the tip of the acromion, the tip of the seventh cervical vertebra, the radial

point, most proximal point on edge of the radial head, styloid point, most distal point of styloid process of radius, ziphoid cartilage, attached to inferior surface of sternum (missing in many females), tip of medius, most distal point of middle finger, tip of the trochanter, most lateral point of great trochanter of femur, tibial point, medial edge of inner tuberosity of tibial head, and malleolar point, distal tip of medial malleolus

There are numerous other landmarks not so commonly used and, in general, more difficult to locate The landmarks selected are determined by the data the investigator wishes to obtain

LINEAR MEASUREMENTS

Linear measurements commonly taken include height, trochanteric height, tibial height, sphyrion height (distal end of medial malleolus), sitting height, sitting height to suprasternal notch, sitting height to seventh cervical vertebra, forearm length, upper arm length, shoulder width, chest depth, chest width, hip width, knee width, hand length hand width, elbow width, foot length, and foot width Linear measurements may be taken with a number of instruments, the most common of them being the flat sliding caliper The sliding caliper may be used to take linear measurements up to 24 inches, or 61 centimeters The sliding caliper constructed of metal is longer and may be used for measurements up to 75 centimeters Either the metal caliper or wood caliper, properly calibrated, is satisfactory for taking linear measurements Another instrument which may be used for linear measurements is the anthropometer which is comprised of several parts that may be joined together for measuring greater distances than may be measured with the sliding caliper The anthropometer may be used for measuring total height, trochanteric height, and tibial height, whereas the flat caliper is not readily adapted to these particular measurements The anthropometer may also be used as a sliding caliper by the use of two attachable arms, a sliding arm, and a fixed arm The flat caliper, however, is easier to manipulate than the anthropometer and is the preferred instrument when there is a choice between the two

The stadiometer which is found in many gymnasiums may be used to measure standing and sitting heights, as may the Broca Plane The use of a square" with the Broca Plane provides the most accurate method for measuring standing and sitting heights

GIRTH MEASUREMENTS

Girth measurements commonly recorded include neck, chest, waist, thigh, calf, arm, and forearm It would be possible to take other girth measurements, but these are most commonly used because they reflect changes that may occur as a result of (1) growth, (2) development as a result of activity,

and (3) atrophy as a result of inactivity Girth measurements should be taken by means of an anthropometric steel tape since other tapes are subject to error as a result of stretching or shrinkage

There are several methods that have been suggested for taking girth measurements, however, the one which best standardizes the technique is that which involves light contact around the periphery of the part measured with no indentation of the skin The major objection to taking girth measurements with pressure is that of causing the subcutaneous tissue and fat to shift when the tape is applied When (1) the proper landmarks are carefully observed, (2) the contact of the tape with the skin is carefully maintained without excessive pressure and (3) the position of the subject is standardized, then an objective and reliable measurement will be obtained

The measurement of the chest and abdominal girths is somewhat complicated by the excursion of the thoracic cage during normal breathing For this reason, the excursion of the chest (and abdomen) may be followed during quiet breathing and the mean of the largest and smallest measurements recorded

FAT MEASUREMENTS

Fat measurements frequently taken include front of chest, back of chest, abdominal, suprailiac, anterior surface of upper arm, posterior surface of upper arm anterior surface of thigh posterior surface of thigh, and along the midaxillary line at ziphoid level These measurements are important because they yield information concerning changes in the total body mass that are influenced by increments or decrements in body fat and subcutaneous tissue and also, a correction factor may be computed from fat measurements so that more accurate measurements of certain girths may be obtained Fat measurements are used, too, in determining the specific density of the body

Instruments for evaluating subcutaneous tissue and fat are generally known as fat or skinfold calipers The caliper used most commonly has been the Franzen, and it has proven satisfactory to most investigators in the measurement of subcutaneous tissue and fat Recently, however there have been a number of new calipers developed that will eliminate the error attributed to the spring in the Franzen type caliper

Three of the newer types of calipers are the C shaped scissor caliper designed by Best (1) the Harpenden caliper (49), and the newer C shaped scissor caliper developed at Minnesota [1]

It is important in using any of the calipers that a recommended pressure of 10 grams per square millimeter (7,21,23,49) should be maintained It is also important in taking skinfold measurements that the measurement not be repeated over the same area within a short period of time, particularly in the overweight subject It is possible to take successive measurements and to

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obtain a smaller measurement each time on the overweight subject The same problem would not be encountered in a mesomorphic or ectomorphic type person Pascale (40) and Brozek (46) have presented regression equations to determine body density from fat measurements The equation developed by Pascale (40) and a number of his associates at the Army Medical Nutrition Laboratory is

$$\hat{Y} = 1\ 088468 - 007123X_1 - 004834X_2 - 005513X_3$$

$\hat{Y}$ is the estimated body density, X_1 the skinfold measurement on the chest on the midaxillary line at the level of the ziphoid X_2 the skinfold measurement for the chest at the juxta nipple position and X_3 the dorsum of the arm, midway between the tip of the acromion and olecranon The authors express their belief, based on their measurement of approximately 100 soldiers, that the estimation of specific gravity by the Brozek Keys equation gives values that are too high for young soldiers Keys and Brozek (23) have presented an equation to measure proportion of total fat in the body from the density of the body

$$F = \frac{4\ 201}{D} - 3\ 813$$

McCloy (33), Cureton (12), and Brozek (5) have studied the problem of adipose tissue McCloy has worked out a set of norms for males and females from 4 to 18 years and older Cureton has developed a multiple rating scale for classification, on the basis of adipose tissue, and Brozek has presented preliminary descriptive norms for several skinfold measurements taken on adult men All three authors have computed regression equations that may be used to predict normal body weight The use of this kind of equation is limited because few persons are acquainted with its application

Age, height, and weight tables are a poor substitute for a selected group of variables in predicting weight A regression equation based on age and height falls far short of one that is comprised of such variables as chest girth, hip width, fat measurements, and height

Thompson, Buskirk, and Goldman (52) summarized the results of a number of studies that had to do with athletes in respect to skinfold thickness and body density In their study they found that body fat, particularly subcutaneous fat, can be altered by strenuous training, and that body density usually *increases even if no* loss in weight occurs

Kireilis and Cureton (24) used Franzen calipers to measure the external fat of three relatively fat students After six weeks of strenuous running there was a definite trend for the external fat to diminish It was concluded that fat is a real handicap for most strenuous exercise, and also pointed out that weight is not necessarily a good guide in fat loss because fat loss may be compensated for by increased muscle density as a result of exercise In a study by Sills (46), nine students who were overweight, as determined by the McCloy (32) method for estimating normal weight, were given special con

ditioning exercises over a period of four months All 9 of the students were more than 20 percent overweight at the beginning of the 4 month period At the end of the 4 month period the mean loss for the group was 13 pounds or 6 5 percent During this same period the mean gain for these students on a physical fitness test (sit ups pull ups 300-yard shuttle run 100-yard pick a back) was 16.42 points or 148 percent

In unpublished doctoral dissertations by Klotz (25) and Brady (3) the problem of dead weight was studied In both studies it was found that the addition of dead weight to the normal body weight of the individual resulted in poorer performances From these studies it would seem advisable that any subcutaneous fat and tissue in excess of a normal amount should be removed from the body of the athlete through strenuous training and diet if he wishes to attain his maximum performance

Skinfold measurements are taken to determine the amount and location of body fat This information is useful to the nutritionist and physician in determining the status of the individual s health and to the physical educator in attempting to associate body fat with physical performance or to provide fitness counseling Records of skinfold measurements should be included in all longitudinal studies of growth since they provide valuable information not readily discerned from any other source

PHOTOGRAMMETRIC ANTHROPOMETRY

As a result of Sheldon s (43) utilization of photographs in his study of body types a number of investigators have developed techniques for obtaining anthropometric measurements directly from photographs Tanner and Wiener (50) examined the reliability of the photogrammetric method and described a technique for the use of a miniature camera Dupertuis and Tanner (15) considered the posing of subjects for special reference to somatotyping Gavan (16) and his co workers studied the problems of distortion the use of a reduction ratio the focal length of the lens lighting film and other factors to be considered in taking photographs They presented measurements taken on two subjects which they compared to measurements taken from photographs of the same two subjects They concluded that the photographic method is valuable and that it serves to augment rather than supplant the traditional anthropometric methods Geoghegan (17) has presented a system based on photogrammetry for satisfactorily recording ten anthropometric measurements He has also shown that surface area total and partial body volumes as well as specific gravity of the body (when weight is known) may be determined by photogrammetric techniques Blesh (2) has worked with a photometric method that has enabled the investigator to obtain four images simultaneously His work has been in the area of posture evaluation and it may be that this technique could be modified for the purpose of obtaining anthropometric data

It seems apparent that photogrammetry will supplant the traditional methods of measurements when possible The major advantages lie in the ease with which the measurements may be obtained, and in the excellent record which is provided by a photograph

BODY TYPES

From the time of Hippocrates, about 400 B C, there have been numerous attempts made to classify individuals according to body types The majority of these classifications have been based upon either a dichotomy or trichotomy The weakness in this type of classification is obvious, since it is impossible to take the many variations of body types found in a population and place them in one, two, or three categories As more categories are added, the easier it becomes to classify body types Sheldon (43) has presented a method whereby all body types may be classified on the basis of the three components of endomorphy, mesomorphy, and ectomorphy In this system allowance is made for varying amounts of each of the three components within a given individual The rating scale from one to seven makes it possible to use numerous combinations of the three components so that any population can be somatotyped (body typed) There has been controversy about the derivation of the terms (20) which Sheldon uses, and there have been questions (28) concerning whether or not body types, when rated by this system, may be changed A number of investigations have disclosed that the three components are not functionally independent, and therefore, any alteration in one component through a gain or loss in weight, or through muscular development, will have an effect upon one or the other of the remaining two components

Newman (38) used the data that were obtained during an anthropometric survey that was conducted in 1946 by the Quartermaster Corps at Army Separation Centers Forty thousand subjects were photographed and later body typed at Harvard University under the direction of Professor Hooton Hooton's method of typing the subjects varied from that of Sheldon, however, the same components of fat, muscle, and leanness serve as the bases for classification Newman concluded that definite although limited changes are associated with age

Sills (44) in a study of body types and physical performance found that ectomorphy and endomorphy were not independent A bipolar factor was identified with positive loadings for endomorphy and negative loadings for ectomorphy Subsequent studies by Howells (18) and by Lorr and Fields (31) have apparently verified this analysis

Howells concluded that the three factors which were found did not correspond to Sheldon's three body components, and that endomorphy and ectomorphy are not really independent on one another He suggested that additional work be done to discover metrically whether or not there are other

components not covered by Sheldon's system Lorr and Fields did a factorial study of hospital patients and found three distinguishable groups and two person body factors On the basis of a bipolar factor for endomorphy and ectomorphy, they also concluded that it would be more simple and economical to define the somatotypes identified by Sheldon in terms of only two factors rather than three

It seems unlikely that a system of body typing will ever be developed that will be universally acceptable to all people interested in the problem of body types Yet, at this time the system which Sheldon devised has, without question, been adopted by more scientists for the purpose of anthropometric studies than has any other system of typing

ANTHROPOMETRIC INDICES AND BODY BUILD

It has been found that combinations of certain anthropometric measurements vary according to the normal curve of probability, and that an indication of stockiness or linearity of body build may be found by the use of these indices It does not follow, however, that the combining of two or three measurements is a satisfactory method of rating body build A simple example should serve to clarify this statement If two subjects each weigh 190 pounds and both subjects are 5'10" tall, then on the basis of a height weight index these two individuals would fall at the same place on a normal curve, and would be given the same rating It is quite possible that one of the subjects would be of a very muscular build while the other may be very obese It is readily seen, without additional information, that this method of iden [illegible]

[illegible] body build, McCloy (33) has suggested the following two indices as being the best for this purpose

$$(1)\quad \frac{1000\sqrt[3]{\text{weight (kg)}}}{\text{height (cm)}} \qquad \text{and} \qquad (2)\quad \frac{10^6 \times \text{weight (kg)}}{\text{height}^4\ \text{(cm)}}$$

Sheldon (43) has made use of the reciprocal ponderal index $ht/\sqrt[3]{wt}$ in somatotyping and has found the index to be useful in the classification of body types This index alone, for the reason given above, is not sufficient to provide an accurate rating and may be used only as a guide

SOMATOTYPES AND PHYSICAL PERFORMANCE

Cozens (11), Cureton (12), Lindegaard (30), Miller (36), Sills (46), Tappan (51) and Willgoose (53), and Tanner (49), to mention only a few, have examined the relationship between body types and physical performance

The studies which have been done relative to the relationships between body type components and physical performance have indicated the following to be true First, the endomorphic individual is characterized by an excessive *amount of weight which is a limiting factor in the* performance of most skills The "dead weight" which the endomorphic individual carries around with him is a serious handicap Second, the ectomorphic individual is muscularly weak, relatively speaking, and subject to injury so that the types of contests and sports in which he may participate at a highly competitive level are limited by his body type And third, the mesomorphic individual is characterized by physical ruggedness and strength that, without question, are conducive to excellent physical performance

One additional factor in relating body type to physical performance which is not taken into consideration by the Sheldon method of somatotyping is [illegible]

basketball player There are individuals 5 feet tall and 6 feet tall with identical body types This is not common, but it is possible when they are somatotyped by Sheldon's method No additional anthropometric measurement [illegible]

types and under each category he has indicated the type of activity most closely associated with the various body types This table could be extended into more categories, and the somatotypes grouped more homogeneously so that the relationships between body types and performance could be more clearly defined

Sills (47) has presented a method for reducing a large number of categories to a smaller number when comparing body types to performance on physical fitness tests This method, which may be subject to modification and improvement, provides a more valid technique for associating performance with body type than does the technique of observation There are relatively few studies of the relationship of body type to skill in specific sports *that are based upon scientific study*

In the majority of studies, outstanding performers are somatotyped and it is then reported that certain somatotypes are associated with a particular sport It does not follow that there are no other body types that may be associated with success in the sport under consideration

ANTHROPOMETRIC MEASUREMENTS AND PHYSICAL PERFORMANCE

Since Kohlrausch (26) took anthropometric *measurements on more than* 300 Olympic athletes in 1929, there have been numerous studies made in an effort to associate bodily measurements with physical performance DiGio-

vanna (14) found marked differences between the structural and functional measurements of various athletic groups and of a nonathletic group Parnell (39) used a set of measurements taken by Tanner on members of the Oxford University Athletic Club Parnell acknowledged the inadequacy of his sample but reported the following interesting facts the shortest mean subischial leg length was found in a control group of college men, slightly longer in sprinters greater still in long distance runners, hurdlers and high jumpers, and greatest in discus, javelin and shot put groups He used the body build ratio of height/$\sqrt[3]{weight}$ and found that it tended to differentiate the 100 yard dash men from the quarter milers And finally, by using the product of the transverse diameter of the heart, the ratio of height/$\sqrt[3]{weight}$, and subischial leg length it was possible to get even a clearer differentiation between sprinters and long distance runners

Cureton (13) studied champion athletes and found that typical track men are slight in skeletal framework with a relatively longer upper leg ratio, and a longer leg to trunk relationship He also noted that most good sprinters have narrow hips and that the more ponderous men with longer and larger trunks, but with relatively short limbs, are most likely to succeed in weight lifting wrestling, gymnastics, and diving However, this type of classification relative to bodily structure can probably not at present be considered definitive For example, Kroll (28) studied 36 Big Ten varsity wrestlers and concluded that American amateur athletes of this type are not ponderous Rather they tend to be an agility type athlete with an ectomorph mesomorph rating (3-5-4) Krakower (27) found that the expert jumpers were taller than the average nonathletes, that their legs were longer, and they had a wider breadth of foot

Metheny (35) studied the differences between Negro and white athletes in respect to their body measurements The results indicated that superiority in certain sports events might be attributed to these differences A more exhaustive comparison of Negro and white athletes is needed to clarify this area of investigation

A number of studies have been done relative to strength and anthropometric measurements Morris (37), Tanner (49), and Clarke (10), to mention only a few, have done work in this area Since physical performance is highly correlated with the strength and leverage of the muscles of the body, these relationships will no doubt be the subject of intensive and continuing research

MASCULINITY AND FEMININITY

Sheldon (43) has suggested that in addition to giving body type ratings based on endomorphy, mesomorphy, and ectomorphy, the subject be given a rating for gynandromorphy, the degree to which he possesses the characteristics of the opposite sex In working with male subjects, Seltzer and Brouha (42) have presented four masculine component groupings They give the

criteria for evaluation, and present illustrations for each of the four groups Carpenter (8,9) used statistical methods based on anthropometric measurements as a means for determining the masculinity and femininity of body build By taking measurements from a sample of men and women she determined the averages for each of the measurements for both the men and the women She then developed a table from which the degree of femininity or masculinity could be determined

It is unfortunate that the information available is not used and that more research is not being done concerning the influence of secondary sex characteristics in relation to physical performance It is quite obvious, from observation, that most girls who possess certain male characteristics in regard to bodily structure can perform some physical activities better than those who do not, and that males who possess a high degree of femininity in bodily structure are inferior to those who are more truly masculine in body type There is little doubt, too, that many 'masculine' females can perform better in sports than "feminine' males

The utilization of a practical method for estimating masculinity and femininity should be effective in reducing the 'misclassifications' of activity groups for which physical educators are frequently criticized As indicated earlier in this discussion, age, height, and weight do not provide adequate bases for classification, and it may be that an accurate estimate of masculinity and femininity would provide at least some of the additional information needed to avoid serious errors

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4 CHARLES H McCLOY

The Mechanical Analysis of Motor Skills

SUMMARY

The teaching of all sports skills should be according to mechanically correct principles otherwise slow progress and even failure on the part of the learner must be expected Practicing incorrect skills merely serves to guarantee that mastery will be impossible and inefficiency of movement inevitable

Prerequisites for the economical learning of skills are (1) sufficient strength to perform the task, (2) clear knowledge of how the skill is to be performed, and (3) an adequate kinesthetic sense and ability to coordinate the body and limbs to permit accurately controlled movement For his part, the teacher of sports skills should (1) know the possibilities and limitations of the anatomical structures of the learner, (2) know the correct techniques of performing each activity, and (3) teach the mechanical principles involved in the various types of activities to the learners in a way that is appropriate to their intellectual level, and (4) indicate to the learner how specific mechanical principles may be transferred to the learning of related skills

Nine representative mechanical principles of movement are presented in the following discussion, and these are followed by examples of their application in (1) batting a ball, (2) driving in golf, and (3) putting the shot

If teachers utilize the known mechanical principles which govern the quality of movement, they can not only more effectively direct and accelerate the learning of pupils, but also can more readily recognize and correct errors made by pupils On the other hand, if learners are taught the principles of movement, they can then understand their application in mastering new activities, and thus they are better able to learn new skills on their own and serve as teachers to others when trained teachers are not available

Initiative on the part of individual teachers to master the fundamentals of both teaching skills and other aspects of physical education is essential if progress is to be made towards a greater degree of physical literacy

Thirty eight years ago the author of this chapter started with 24 principles relative to the mechanics of human movement in sports, and since that time he has increased this number to 71—and in all probability still others remain to be discovered Moreover, there is no doubt that a great deal more research is needed to round out present knowledge of the mechanics of sports skills In many sports it is assumed that the techniques of outstanding performers are mechanically correct, whereas as a matter of fact exceptional performance by a talented person may be in spite of rather than because of his technique Experimental studies are needed in many sports and in various aspects of some sports to establish the superiority of specific movement techniques

To insure constant progress towards physical or motor mastery the teacher should proceed according to correct mechanical principles

When, as is so commonly observed in physical education classes, the pupils make slow progress in the learning of the correct techniques of motor skills very often one of the reasons is that the pupils do not understand what they are trying to learn, and are often trying to learn a skill incorrectly because they think (erroneously) that this incorrect objective of learning is the correct one One of the best ways to insure the pupils having the correct objectives is to teach the activities in such a way that the mechanics of each type of skill is clear not only to the teacher but to the pupil

The teaching of the techniques of gymnastics, and of many sports involving such activities as running, hurdling, jumping, throwing the discus, throwing a ball, kicking a football, swimming, or diving, has been highly developed empirically, but the mechanical principles upon which these techniques are based are frequently only vaguely understood and most of the teaching is based on tradition and on trial and error learning—and not infrequently the teaching is erroneous Numerous books on track and field athletics, on basketball, on baseball, and on other sports contain many erroneous statements of fact If the athletes wishing to master these skills were to follow the directions given by the authors often mastery would be impossible, because the directions are incorrect

To learn such skills economically, the following prerequisites for the learning situation would seem to be essential

1 The learner must have muscular strength adequate for the performance of the task For example, a person who lacks strength enough to pull himself up by his arms or to flex the thighs forward on the trunk against the resistance of gravity and centrifugal force could not succeed in learning to perform difficult exercises on the horizontal bar, the parallel bars, the horizontal ladder, or the flying rings A person with weak arms will not be able to put the shot or throw the discus successfully

2 The learner must know clearly *how* the skills should be performed, otherwise he is apt to be trying (all too frequently successfully) to learn the *wrong* coordination—and, of course, will fail to learn the activity correctly

3 He must have developed through previous practice of gymnastics or sports an adequate kinesthetic sense and an ability to coordinate his body and limbs to enable him to control all parts of his body to the point where he can cause them to obey his will This means, of course, that from the very beginning of the teaching of physical education skills in the schools, the progression must not be too rapid and the technique of the skill must be correct

From the standpoint of the teacher the following abilities are desirable

1 The teacher should know the possibilities and the limitations imposed by the anatomical structures of the learners For example, the limitations of the backward movement of the femur in the acetabulum imposed by the ilio femoral ligament limits the effective length of the forward stride of the opposite leg in such movements as batting the baseball, and often causes the batter to be moving backward away from the approaching ball when attempting to strike it Another example is the limitation imposed by short, biarticular muscles on the backs of the thighs (biceps femoris, semitendinosis and semimembranosis) of the effective performance of a hurdler a high jumper, a diver a gymnast, or a dancer

2 The teacher should know the correct techniques of performing each activity He should know how to detect and rectify all incorrect performance This is best accomplished by learning the mechanical principles that can be applied to the skills of physical education, by learning how to apply them, and by learning what happens mechanically when the activity is incorrectly performed When any athletic or gymnastic activity is correctly performed, the mechanics of the performance is correct, if they are incorrectly performed, the mechanics of the activity is incorrect

3 The teacher should teach these mechanical principles to the performers, often in a very simplified manner and using a simplified vocabulary—particularly when teaching young children—so that they understand not only what they are trying to learn, but how the activity is to be performed, and why this method of performing the activity is correct This use of mechanical principles and the accompanying explanations can readily be made even with children as young as 10 or 12 years of age

4 When learning these mechanical principles, the teacher should indicate how such skills may be transferred to the learning of related skills for example, how one who has learned the principles of batting a baseball may apply that learning (in terms of mechanical principles) to the learning of the drive in golf, or of a forehand or backhand stroke in tennis, or of the kicking of a football Most of the mechanical principles used

in each of these activities should be almost entirely the same, and the learner can apply these principles to different related activities when he takes them up at a later time, often without the benefit of a skilled teacher.

It may be helpful at this time to present several illustrations Nine simple principles will be presented here and in turn all or almost all of them will be applied to a number of different athletic events This will show, further more, how these principles can transfer from one activity to another

PRINCIPLES

1 The first principle presented is that in most striking, throwing, or kicking movements the mass of the body should be moving in the direction of the hit, throw, or kick

This results in adding effectiveness to activity for if the body is moving forward, the forward velocity of bat, golf, club, tennis racket, foot, etc will be greater than if the body is not moving forward, or if it is even moving backward [1]

2 Additional force is given by the torque transmitted from the feet on the ground or the floor through the rotation of the thighs at the hips, and the rotation of the trunk around the spine, and finally transmitted through the shoulders and arms

In the case of kicking, torque is transmitted through a leg to the foot that contacts the ball In the case of kicking a football, the torque tends to be partially around a transverse axis passing through the hips, with the kicking leg moving forward and the trunk moving backward [2]

3 Frequently, though not always, just before the conclusive part of the performance the individual should adopt what is frequently called an "open stance."

[1] This may be illustrated by the following formula

$$V_2 = \frac{(m_2 - em_1)\, u_2 + (1 + e)\, m\, u_1}{m_1 + m_2}$$

In this formula u_1 represents the approaching velocity of the agent which strikes or

[illegible] movement forward adds to this forward [illegible] greater

[2] In all subsequent descriptions, it will be assumed that the performer is right handed, and that he kicks with the right foot

For example, in the case of putting the shot, after the individual has executed the hop and after the right foot comes to rest on the ground, the left foot should not be directly in the line of direction of the throw, but should be about 6 to 10 inches to the left of that line This gives a larger angular distance for rotation of pelvis and trunk, and permits the movement supplying the torque to be carried further in a counterclockwise direction

4 In almost all cases more than one force will be applied, and usually those forces are not equal in size

For example, in the shot put, after the hop, there will be the torque and forward motion supplied by legs and trunk, which is a very powerful force, and this force will be blended as its acceleration decreases into the movement of the upper arm around the shoulder joint in a forward and upward plane, and this in turn will be followed by the vigorous palmar flexion of the hand Quite obviously the strength of the flexion of the hand is the weakest of these three forces The muscles that move the upper arm forward and upward are the next weaker, while the muscles which supply the torque and forward movement of trunk and body are the strongest If there was an effort to apply all of these forces simultaneously, the force of the muscles which supply the torque would be so strong as to overwhelm the forces of the other two groups because of the increased reaction resulting from the large increase in the acceleration of the shot The principle applied here is to delay the beginning of the use of the arm and shoulder muscles and later of the palmar flexors of the hand until the acceleration produced by the previous force has diminished to the point where the strength of the groups of muscles just mentioned can be applied effectively [3]

5 To permit the implement (bat, golf club, tennis racket) or the hand or foot to move through a longer arc in order to permit the applied force to accelerate the implement, hand or foot to a greater velocity, the arm forearm, hand, thigh lower leg, etc are moved in such a way that the limbs are sharply bent at certain joints

For example, in swinging a golf club, not only are the arms raised sidewards and upward to the right, but the hands are radially flexed so that [illegible] lirection of the intended [illegible] (or as a tennis racket is [illegible] forward) the limbs are straightened at these joints, thus the implement, hand, or foot is enabled to travel through a greater distance before touching the ball or releasing the ball in a throw In the golf swing, as the arms swing downward and to the left in a circular plane tangent to the intended flight of the ball, the hands are ulnar flexed forcibly in such a way as to accelerate the angular

[3] Here the formula Force = mass × acceleration is the one that applies When acceleration is great the forces of both action and reaction are great when the acceleration has diminished the forces diminish and the succeeding force can be applied effectively

movement of the golf club downward and thus to increase its velocity at impact In a similar way in kicking a football, as the thigh is flexed forward, the lower leg is extended rapidly, enabling the foot to travel over a greater distance and to achieve a higher velocity before impact

6 Just prior to impact or just before the releasing of a ball in the act of throwing it, the movement of arms and hands, or legs and foot, should be forcefully emphasized to the point where the individual "hits through" the ball or "kicks through" the ball

This is important because there is often a psychological tendency to anticipate the impact and to decrease the amount of force applied

7 In striking or throwing movements in which a great deal of force is applied on an object of considerable weight, such as putting the shot, throwing the discus, or batting a ball, the rear foot should remain on the ground until the implement has left the hand or the ball has left the bat

The reason for this is that in making the strong effort needed to throw the discus, put the shot, or to swing the bat as hard as is necessary the reaction of this movement is so great that it is likely to greatly retard the forward movement of the body or even to push it backward Keeping the rear foot on the ground obviates this difficulty and prevents the reaction of the throw or swing of the bat from moving the performer backwards This is not important in the case of the throwing of such light objects as a baseball or cricket ball or javelin, as the mass of the ball or javelin is so small relative to the mass of the performer that it is preferable to obtain as much forward momentum of the body as is possible, which gains more for the performance than is lost by prematurely removing the rear foot from the ground This principle does not, of course, apply to kicking activities where that foot is used as the "implement" with which to kick the ball

8 The hit or throw should be performed at the correct angle When hitting a baseball, for example, gravity causes the ball to fall from the highest [illegible]

so that the ball will clear the net without being pulled down into the net by gravity This, of course, does not apply to the tennis smash or volley from a position near the net In putting a shot at the world's record distance, the proper angle is about 40° from the horizontal

9 There should be a "follow through" after the conclusion of the performance of batting, throwing, or kicking in order to diminish the amount of force taken to stop the body or limb *

[illegible]

For example, in the case of putting the shot, after the individual has executed the hop and after the right foot comes to rest on the ground, the left foot should not be directly in the line of direction of the throw, but should be about 6 to 10 inches to the left of that line. This gives a larger angular distance for rotation of pelvis and trunk, and permits the movement supplying the torque to be carried further in a counterclockwise direction.

4. In almost all cases more than one force will be applied, and usually those forces are not equal in size.

For example, in the shot put, after the hop, there will be the torque and forward motion supplied by legs and trunk, which is a very powerful force, and this force will be blended as its acceleration decreases into the movement of the upper arm around the shoulder joint in a forward and upward plane, and this in turn will be followed by the vigorous palmar flexion of the hand. Quite obviously the strength of the flexion of the hand is the weakest of these three forces. The muscles that move the upper arm forward and upward are the next weaker, while the muscles which supply the torque and forward movement of trunk and body are the strongest. If there was an effort to apply all of these forces simultaneously, the force of the muscles which supply the torque would be so strong as to overwhelm the forces of the other two groups because of the increased reaction resulting from the large increase in the acceleration of the shot. The principle applied here is to delay the beginning of the use of the arm and shoulder muscles, and later of the palmar flexors of the hand, until the acceleration produced by the previous force has diminished to the point where the strength of the groups of muscles just mentioned can be applied effectively.[3]

5. To permit the implement (bat, golf club, tennis racket) or the hand or foot to move through a longer arc in order to permit the applied force to accelerate the implement, hand or foot to a greater velocity, the arm, forearm, hand, thigh, lower leg, etc., are moved in such a way that the limbs are sharply bent at certain joints.

For example, in swinging a golf club, not only are the arms raised sidewards and upward to the right, but the hands are radially flexed so that the golf club points approximately toward the direction of the intended flight of the ball. As the arms are brought down (or as a tennis racket is swung forward or the leg in kicking is swung forward) the limbs are straightened at these joints, thus the implement, hand, or foot is enabled to travel through a greater distance before touching the ball or releasing the ball in a throw. In the golf swing, as the arms swing downward and to the left in a circular plane tangent to the intended flight of the ball, the hands are ulnar flexed forcibly in such a way as to accelerate the angular

[3] Here the formula Force = mass × acceleration is the one that applies. When acceleration is great, the forces of both action and reaction are great; when the acceleration has diminished, the forces diminish and the succeeding force can be applied effectively.

The Drive in Golf It will readily be seen that the same principles will apply to the striking of a golf ball

1 There is no step forward, but there is a lateral shift of mass from the right to the left as the swing progresses
2 The torque is around the long axis of the spine and the hip joints, and around an anteroposterior axis through the spine as the left arm swings downward and to the left with the change of the lateral curve of the spine from a left curve to a right curve
3 Usually there is no open stance here as the hitting is in front of the body and there is ample room to complete the pre impact swing before coming to the end of the active muscular contraction
4 The application of forces is first, the lateral sway to the left then the application of the torque, then
5 The swing of the arms downward accompanied by the ulnar flexion of the hands just preceding the hit
6 The individual should hit through the ball for at least a few inches after the club head has made contact with the ball
7 The rear (right) leg should be kept straight and the ball of the foot should remain on the ground and push strongly downward and to the right until after impact with the ball
8 The player should hit straight through for a drive, but should hit downward slightly for his iron shots (this involves another principle which will not be gone into here)
9 The follow through is for the same purpose as that described above

Putting the Shot In a shot put the same principles apply

1 There should be a hop on the right foot of a right handed thrower, moving to the front of the circle and a tipping of the whole body on the right foot in the direction of the throw so that as the individual prepares to put the shot, the whole body continues to rotate counterclockwise around an anteroposterior axis through the right foot The body should thus continue to move in the direction of the anticipated put as the subsequent forces are added
2 There should be an application of torque as indicated above in batting
3 There should be a placing of the forward (left) foot about 8 inches to the [illegible]
4 [illegible] with its accompanying [illegible]
5 The successive movement of the upper arm in a forward and upward plane (with wrist in front of elbow), followed by the forceful palmar flexion of the hand at the end of the throw
6 The individual should keep pushing the shot throughout until it has left the hand

7 The rear foot should remain on the ground until the put has been com pleted [a]
8 The angle of the shot to the ground for the world s record distance should be about 40 degrees The angle should be slightly greater for shorter dis tances
9 The reverse and follow through exemplifies the same principles as those indicated above in the discussion of the principles

Some Exceptions There is not space here to analyze all of the activities that have to do with throwing striking or kicking There are some dif ferences in different performances in some of which one or more of these principles are not applicable For example in the throwing of light balls or of the javelin as indicated above, the rear foot should not remain on the ground as the mass of the body is so much greater than that of the ball or javelin that it is more efficient to develop a larger amount of forward mo- mentum and to neglect the relatively minor force of reaction produced by the throwing of the ball or javelin

Obviously in kicking a football only one foot can remain on the ground during the kick

In such an activity as a backhand drive in tennis not only is there no open stance but there is a decided closed stance or a stepping across with the for ward foot This is to permit a larger range of movement of the right arm and racket before it hits the ball and thus to enable a greater amount of velocity to be developed while the arm and racket are accelerating over this increased distance

In 1922 this writer began the study of mechanical analyses of motor skills with a list of 24 mechanical principles This list has grown through the years until he is now using 71 such principles and subprinciples and the list will probably grow much longer in the future as more study is given to the analysis of other activities

TRANSFER OF LEARNING

It may readily be seen that if these principles are taught to the learners (us ing where necessary a simplified terminology in keeping with the educa tional progress and abilities of the pupils) these learners can readily under stand the application of these principles to the mastery of new activities For example if a boy has learned to bat a baseball he can readily learn to hit a

[a] his hand

golf ball well and to kick a football accurately if he applies these common principles intelligently

This method of teaching (1) aids the teacher in teaching new skills The teacher not only knows how to direct the learning of the pupils, but he more readily recognizes the errors made by the pupils and the causes thereof (2) It also aids the learner himself to master new skills more readily in situations where he has no competent teacher, when, for example, he has no competent teacher of golf but 100 poor golfers all eager to show him how to perform incorrectly! (3) Finally, it aids the learner to become a more trustworthy instructor of others when a trained teacher is not available

It is the writer's belief that wider applications of the mechanical analyses of all skills pertinent to physical education will lead to better teaching of these skills, and to about twice as rapid learning upon the part of the learners Teachers of physical education or gymnastics should give as much attention to developing such a scientific method of teaching sports and other athletic skills as they have given to the teaching of the more formal gymnastic skills

It would seem to this writer that there are two very important aspects to be adequate teaching of skills One is the application of the proper psychological principles, and the other is the application of the proper mechanical principles of analyzing the skills to be taught

In addition to these, of course, there is the extremely important item that the teacher shall at all times be alert, first to note the needs in the teaching of each pupil so that the teacher may first present the skills in such a way that they are most easily learned, and second, to correct errors as soon as they occur so that the pupil does not continue to learn the incorrect applications of psychological or mechanical principles

One cannot, in the space of one short chapter, present a series of semester courses in Principles, in Methods, in the Psychology of Physical Education, and in the Mechanical Analysis of Motor Skills It is only as the teachers become interested in studying in these areas, and perfecting their knowledge and abilities in these areas, that progress will be made towards a greater degree of physical literacy[7]

RESEARCH NEEDS

Material covered in this chapter is very partial and deals with only one aspect of the field of the mechanical analysis of sports medicine The book reference cited (Bunn) covers a great deal more of the same subject However, the writer feels that very much more research should be undertaken to push the knowledge of the mechanical analysis of sports skills in the next

[7] For further materials see John Bunn *Scientific Principles of Coaching* New York Prentice Hall, 1955

few years As stated above, the writer originally, in 1922, started with 24 different principles He now has accumulated 71 principles, and is not at all sure that he has covered everything It would seem highly desirable that further research be done not only to discover new principles, but to make more accurate application of these principles to different sports An example of this might be seen in the change in the form of the shot put Not too long ago, the shot putter stood with his left side to the front of the ring, hopped to his left, and then completed the put Now the approved form seems to be with the back toward the circle, and hopping backwards, and later turning to have the larger angular movement take place before putting This new form has not been experimentally validated so far as the literature is concerned It may have been simply the fact that a man with adequate strength and agility was able to exploit this form, where he might have had equal success with the old form It would seem to the writer that experimental studies on a number of expert putters should be exploited This would be only one example of dozens of activities which need special research done upon them

PART II

Physiological Aspects of Exercise and Sports

5 EDWARD F. ADOLPH

Some Physiological Regulations Illustrated in Exercise

SUMMARY

The aim of this chapter is to characterize some of the automatic regulations of cellular and bodily activities Dramatic instances of inherent controls can be described as they occur in muscular exercise When a muscle contracts its physical and chemical activities are suddenly speeded up as [illegible]

fectors of the system, but also in terms of quantitative relations between demand and supply At the end of a steady state of exercise, recoveries to the resting state again reveal how the activities are modulated so that the initial state is restored The description of these relations between intensity of work and modification of activity reveals the patterns of bodily and cellular organization both for maintenance at rest and for coordinating various intensities of physical activity

INTRODUCTION

When a muscle contracts it does so with a particular rate, force, and duration Without nerves the muscle is paralyzed But when impulses arrive through the nerves a number of processes are immediately speeded up At least twelve enzymes act in series to gear energy into contraction (8) Hence in the muscle at rest, one or more of the enzymes handling electrons is probably unavailable, in an inactive form, until the train of excitation processes is started Control of the muscle implies control of all the steps in its energy transformations as well as in its overt contraction Such self regulations attend every movement, both voluntary and involuntary Almost the whole body and its far flung processes of circulation, respiration, and nervous

activity participate in hundreds of such controls making the study of regulations a comprehensive one

Within the nervous system specific controls are easily recognized A muscular system without autogenous reflexes would be like an automobile without a man at the steering wheel Regulation means steering accelerating stopping and repairing The study of contraction as a process or excitation as a discrete event resembles the testing within the automobile of a single cylinder s performance In fact only when parts and processes operate together is the automobile s output effective It is effective when output is graded to varied circumstances perhaps through automatic choke automatic gear shift automatic throttle and automatic steering

Without built in controls a circulation of blood would be as wild as an infant s first performance on the piano The delivery of blood would follow no pattern and accomplish no result In detail the pressures in the blood vessels would show no constancy the regional distribution of blood flows would be random (and largely dictated by gravity) and the total blood pumped by the heart would bear no relation to the demands of exercise

When a living process comes to notice two kinds of physiologists examine it One asks How does it work? His kind tries to identify the type and parts of machinery represented The other asks What starts and stops it or speeds or slows it? His kind tries to learn how the process modulates with circumstances The curious fact that the same physiologist rarely regards the process with equal emphasis from both aspects seems to require a separate emphasis on regulatory phenomena Sometimes this aspect is designated by the term *regulatory physiology*

The concept of regulation is familiar today because automatic gadgets work for us Only a century ago control devices were so rare that regulations in everyday living required human attention—house heating water supply timekeeping street lighting Now a man may grow up in the midst of machines that control themselves and he has no difficulty in picturing self governing systems as being natural instead of supernatural

The study of controls sometimes consists of tearing the machine apart to see its structure In addition study may be given to its intact operating characteristics The latter study is e

A number of ways can be identifie

isms generally are described From

bodily control systems may be partially discerned

Frequency of Heartbeat Pulse counts are the most frequently measured of all physiological parameters Here we inquire what they can tell us about regulations No doubt heartbeats are counted so often because they yield useful information That information concerns (1) their constancy hence their overall controls under standard conditions and (2) their changes in relation to numerous conditions known or unknown Here we will watch pulse rates at rest during a bout of exercise and immediately after it

In an individual who counts his pulse frequency each morning before he arises, the coefficient of variation (CV = standard deviation/mean) is 7 8 percent This means that two thirds of the counts fall between +7 8 percent and −7 8 percent of the mean (11) This deviation signifies that all controls of pulse frequency act together more often than not to prevent wider de

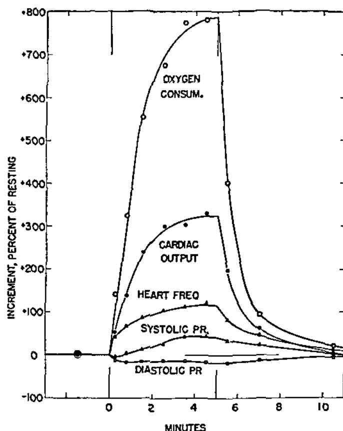


FIG 5 1 *Courses of five properties of a man during 5 minutes of physical exercise and during subsequent recovery Data of Iljin Kakujeff* (14) *as reproduced in Adolph* (1, 353)

partures from the mean The smaller the variation, the more precise is the regulation

When the same individual stands up, his pulse per minute increases from 63 to 88 on the average The CV of pulse frequencies remains about the same, 8 7 percent, which fact suggests that regulators are equally adequate in this posture, and that constancy of pulse frequencies is not being sacrificed in the interests of regulating other factors such as cardiac output or

arterial pressure All the above represents an evaluation of a physiological regulation by means of relations to be designated below as *type R*

When exercise begins the pulse accelerates as everyone knows The course of acceleration is worthy of study (Fig 52) While acceleration begins with the very first beat in which bodily movement occurs a new steady frequency is not attained for some minutes (7) Similarly, after the exercise is over appreciable time is required for deceleration We may therefore speak of transitional states between two steady states The measurable rates at which those transitions occur are the speeds with which regulation shifts The first transition is the onset the second is the recovery, and the latter is especially useful for visualizing regulatory responses

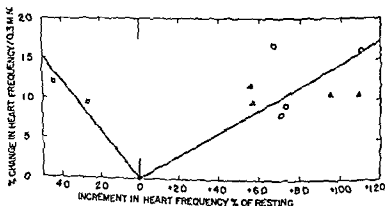


FIG 52 *Acceleration or deceleration of heartbeats in relation to mean frequency of beats Accelerations and decelerations are in percent change of beat frequency during the first 18 seconds of release from stimulation Various data as reproduced in Adolph* (1 351)

When the rates of recovery are plotted against the known departures from resting rates an equilibration diagram is established (Fig 52) It shows that recovery was faster when departure from resting was greater This fact represents a useful property of a recovery The *general picture* is that of a process that reverts in a given period of time to a single value whenever it is released from disturbance These are relations termed *type P*

It is a telling trait of regulation that the final pulse frequency after recovery usually equals the initial control frequency before exercise Everyone expects this to be so but all need to be reminded that a return to a former steady state depends on total controls that are somehow set to a fixed groove

A great deal is known about the processes and structures through which F 1 c thermal chemical and r we know, beats without

external command But in the body the frequency of beats is almost continuously modified through varied influences Nervous influences, for instance, are both inhibitory and acceleratory, traveling to the heart through numerous nerve fibers in which impulses are set up in response to diverse sensations Therefore frequencies may be controlled both by factors such as temperature intrinsic in the pacemaker and by factors such as hormones external to it but playing upon it The important feature of responses to all these influences is that they ordinarily follow an exact pattern, resulting in a heart frequency that is reproducible and is fixed under a given circumstance The constituent processes of controls, such as nerve impulse codes, represent relations of *type T*

Although the above patterns of regulations show what happens to govern the heart's frequency of beat, they do not exhaust the ways of studying regulations Further illustrations may be drawn from the field of respiration

Breathing Respiratory regulations were first approached anatomically, it was found by Galen that the upper spinal cord was necessary for mammalian breathing Centuries later Legallois noted that parts of the brain anterior to the medulla could be dispensed with but not the medulla oblongata itself Still more recently respiratory regulations were approached chemically, since

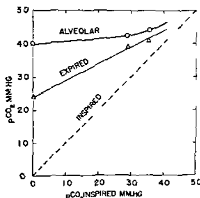


FIG 5 3 *Alveolar pCO_2 and expired pCO_2 as they change with inspired pCO_2 during breathing of air enriched with CO_2 Data of Campbell* et al (6)

amount of breathing or ventilation By correlating the pulmonary ventilation with the partial pressure of each substance, we find that under ordinary circumstances the carbon dioxide pressure (pCO_2) is chief At altitudes pO_2 becomes chief In exercise we are able to define the interrelated roles of pCO_2, pO_2, pH, and metabolisms (10)

The overall resultant of regulation can also be expressed in a "concentration diagram' (relations of *type Q*) When the pCO_2 alone is varied, the automatic responses are assessed in alveolar pCO_2 (Fig 5 3) Or when the pO_2 alone is varied, the effect in blood and in tissues also may be viewed in terms of pO_2 in them (Fig 5.4) In both cases the partial pressure in the tissues does not change as much as the partial pressure in the external atmosphere Tracing the actual relations between the pressures of alveolar oxygen and of inspired oxygen, we find that a convenient measure of the regulation is the slope of the line relating pO_2 alveolar, or pO_2 capillary and pO_2 atmospheric (Fig 5 4) Greater intervention of physiological functions

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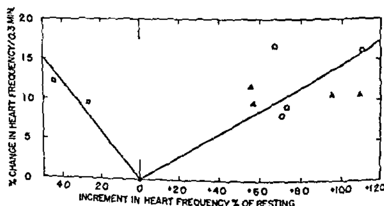


Fig 5 2 *Acceleration or deceleration of heartbeats in relation to mean frequency of beats Accelerations and decelerations are in percent change of beat frequency during the first 18 seconds of release from stimulation Various data as reproduced in Adolph* (1,351)

When the rates of recovery are plotted against the known departures from resting rates, an "equilibration diagram" is established (Fig 5 2) It shows that recovery was faster when departure from resting was greater This fact represents a useful property of a recovery The general picture is that of a process that reverts in a given period of time to a single value whenever it is released from disturbance These are relations termed *type P*

It is a telling trait of regulation that the final pulse frequency after recovery usually equals the initial control frequency before exercise Everyone expects this to be so but all need to be reminded that a return to a former steady state depends on total controls that are somehow set to a fixed "groove"

A great deal is known about the processes and structures through which pulse frequency is modified In general, mechanical, thermal, chemical and nervous influences play upon it The isolated heart, we know, beats without

external command But in the body the frequency of beats is almost continuously modified through varied influences Nervous influences, for instance, are both inhibitory and acceleratory, traveling to the heart through numerous nerve fibers in which impulses are set up in response to diverse sensations Therefore frequencies may be controlled both by factors such as temperature intrinsic in the pacemaker and by factors such as hormones external to it but playing upon it The important feature of responses to all these influences is that they ordinarily follow an exact pattern, resulting in a heart frequency that is reproducible and is fixed under a given circumstance The constituent processes of controls, such as nerve impulse codes, represent relations of *type T*

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Breathing Respiratory regulations were first approached anatomically, it was found by Galen that the upper spinal cord was necessary for mammalian breathing Centuries later Legallois noted that parts of the brain anterior to the medulla could be dispensed with, but not *the medulla oblongata itself* Still more recently respiratory regulations were approached chemically, since [illegible] amount of breathing or ventilation By correlating the pulmonary ventilation with the partial pressure of each substance, we find that under ordinary circumstances the carbon dioxide pressure (pCO_2) is chief At altitudes pO_2 becomes chief In exercise we are able to define the interrelated roles of pCO_2, pO_2, pH and metabolisms (10)

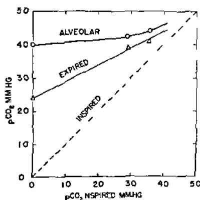


FIG 5 3 *Alveolar pCO_2 and expired pCO as they change with inspired pCO_2 during breathing of air enriched with CO_2 Data of Campbell* et al (6)

The overall resultant of regulation can also be expressed in a "concentration diagram" (relations of *type Q*) When the pCO_2 alone is varied, the automatic responses are assessed in alveolar pCO_2 (Fig 5 3) Or when the pO_2 alone is varied, the effect in blood and in tissues also may be viewed in terms of pO_2 in them (Fig 5 4) In both cases the partial pressure in the tissues does not change as much as the partial pressure in the external atmosphere Tracing the actual relations between the pressures of alveolar oxygen and of inspired oxygen, we find that a convenient measure of the regulation is the slope of the line relating pO_2 alveolar, or pO_2 capillary and pO_2 atmospheric (Fig 5 4) Greater intervention of physiological functions

results in low slope, or, the internal pO_2 tends towards independence of external pO_2 However, none of the slopes is constant at all pO_2s All the specific events and processes that react to the atmospheric pO_2 and pCO_2 can remain unnamed in this assessment of the overall regulatory result

One need not stop with the correlation of the internal pCO_2 and pO_2 with the external pCO_2 or pO_2 The extent of pulmonary ventilation, in

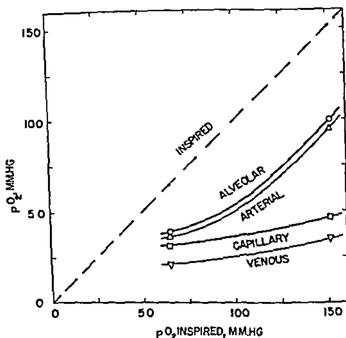


Fig 5 4 *Pressure of oxygen estimated at four points along the path of oxygen transport from inspired air to venous blood The two series of values were obtained in a man at sea level and in a man acclimatized at 20 000 feet altitude Data of Houston and Riley* (13) *The shape of the alveolar curve was obtained from data assembled by Boothby* (5)

consequence of breathing movements, varies with gas pressure Stepwise (relations of *type P1*) one may first relate pulmonary ventilation either with pCO_2 (Fig 5 5) or with pO_2 or with both (10), and since ventilation moves CO_2 and O_2 from and to alveoli relate the rate of CO_2 output with pCO rate of oxygen consumption with pO_2 Second (*type P2*), since pCO_2 is related to the body's CO_2 content, and pO_2 to its O_2 content, one may construct the corresponding equilibration diagrams for the body's CO_2 content (1,341) and for the body's O_2 content (p 344) Third (*type RB1*), the variability of pCO_2 or other resultant of regulation may be ascertained (11) Its correlatives (*type R2*), of course, vary in harmony with

it (15,16) Fourth (*type* S), the behaviors that conserve O_2 when it is scarce, and act to obtain more O_2, convulsively or otherwise, are added Finally (*type* T), activities of the apparatus (chemoreceptors) sensitive to pO_2 and pCO_2, of afferent, synaptic, and efferent nervous transmission of muscular and vascular response, may be measured both in parts and in whole (10) The fractional contribution of each exchange, behavior, and part can be estimated within limits The whole picture of regulation would be a thorough description of mammalian respiration, of which small fragments have been worked out Only certain aspects of those fragments are mentioned here

Interrelations in Exercise So far we have spoken of heartbeat frequencies or pulmonary ventilations as though each were regulated alone But, of course, many physiological changes occur concurrently, as muscular exercise well illustrates Each property that undergoes a change may be termed a component, its increment may be termed a strain

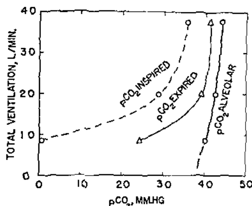


FIG 5 5 *Total ventilation of respiratory tract in relation to* pCO_2 *in air obtained at inspiration, alveoli and expiration Data of Campbell* et al (6)

Five components that respond to exercise are shown in Fig 5 1 One way of comparing them is to designate the resting value of each as 100 percent Then in the grade of work imposed, oxygen consumption increased nearly 800 percent, cardiac output 300 percent, and heart frequency 100 percent The accelerations of the three ran approximately proportional to one another This more or less familiar fact points to the existence of intimate coordination which signifies fine quantitative regulation It may be pointed out that, of course, oxygen consumption could not increase 800 percent without more cardiac output, and the latter could hardly increase 300 percent without faster heartbeats That the several increments or loads are automatically nearly proportioned, represents what predetermined controls do to adjust the increments A suitable method of assessing the relations among the components during exercise is to plot the load of one component (as, oxygen consumption) against the load of another (as, cardiac output) as was actually done (1,405) It there turned out that during the transition from rest to exercise and during the recovery from exercise the same path was traced, showing that the three components maintained ratios at all times In finer analysis the increments of these three components may not always be proportional to one another (9), it appears rather that some other linear

relation holds among them From such a relation alone one is justified in believing that stimuli, produced by the muscular work itself, influence in a quantitatively fixed manner the diverse reflexes, secretions, metabolisms, and mechanical events bearing upon the effector organs for oxygen consumption, cardiac output and pulse frequency

Not all strains of exercise are anywhere nearly proportional to one another, as illustrated by the increments of systolic and diastolic arterial pressures (Fig 5 1) Indeed one pressure increases while the other decreases during the muscular work The numerical difference between the two pressures, or the pulse pressure also is not parallel to the other components in the transitional periods These facts indicate that descriptions of regulatory arrangements cannot all fit one simplified scheme They also imply that the arrangements themselves mesh in ways which cannot be predicted

Each of the components portrayed in Fig 5 1 waxes and wanes in what may be termed a tolerance curve As in a blood sugar tolerance curve, initial disturbance sends the component away from its resting value Various compensations gradually come into play so that the component's value approaches a steady one At the cessation of exercise the compensations, already started effect recovery they taper off exponentially toward the final resting value of each component The course of events appears to be smooth but the number of processes operating behind the scenes is great indeed For instance the recovery of oxygen consumption after exercise can be represented in part as a compound of two oxygen debts, an alactate debt and a lactate debt Each debt has its own rate of onset and of removal that corresponds with a chemical clearance (12) An inference is that the two debts or their thermodynamic representatives are stimuli, each of which dictates an acceleration and later a deceleration of cardiac output, as well as of pulmonary ventilation and of other components

Although the number of components that suffer displacement during a bout of exercise be large, they are evidently linked with one another in a pattern of interlocking controls For example pulmonary ventilation, heart beat frequency, and rise of body temperature are each a part of the exercise syndrome Each increment in a component may be regarded as a strain to which the physiological body is subjected The fact that there are many strains suggests that each one absorbs part of the disturbance One may even imagine that various strains become adjusted in relation to one another so as to result in a sum of strains which is minimal Thus, more rise of body temperature may relieve the circulatory system from a call to respond with a greater increase of blood flow

Comparison of stresses Each strain is a part of the response to an impinging stress In this case a portion of the stress may be the drive that impelled the man to exercise and another portion may be the resulting metabolic and other derangements that departed from control values Some of the physiological components that become strained, such as pulmonary

ventilation (10,57) and heartbeat frequencies (4), appear to accelerate linearly with the degree of metabolic stress or intensity of work

Any one of the physiological strains, such as heartbeat frequency, can be used as a partial measure of severity of various stresses Such use is illustrated by the responses to certain compounded stresses that have been investigated Men who work in hot deserts are subjected to muscular effort, heat, and de-

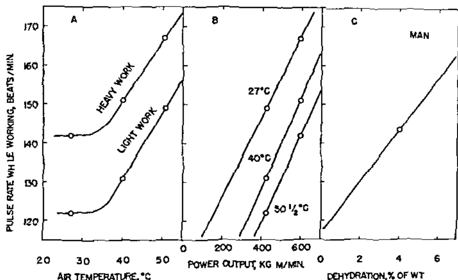


FIG 5 6 *Effects of* (A) *heat,* (B) *grade of work and* (C) *bodily dehydration on pulse rates during work Methods and derivations of data as described in Adolph* et al (2,204)

hydration Counts of pulse rates can be used to compare the stresses imposed by each of them For this purpose men did standard exercises of two work intensities in three atmospheres and while dehydrated by 0 to 7 per cent of their body weights (2) It turned out that the frequency of heart beats was proportional to each of these stresses within wide limits (Fig 5 6) Therefore the slopes of the three diagrams in Fig 5 6 could be read in some such terms as Table 5 1 From the table in turn one can predict the strain

TABLE 5 1 Relation of Increment in Heart Beat Frequency to Three Stresses in Man

Type of Stress	Increase in Stress for ΔStrain* of 1 Beat/Min
A *Air temperature* −32°	0 67°C
B Work rate	9 4 kg m/min
C Bodily dehydration	0 15% weight

* Δstrain = 0 67 (A—32°) + 9 4 B + 0 15 C

imposed on the average man by each stress mentioned Two or three stresses superimposed can also be estimated by the addition of the empirical factors listed

One further step is informative, stresses that gave equal accelerations of heartbeat may be said to be equivalent to one another The equivalences thus estimated (Table 5 2) reveal relative effects from otherwise incommensurate quantities of work, heat and dehydration The list could be extended to other forms of stress such as posture, radiation, clothing, and humidity Erroneous conclusions would be reached however, if one supposed that all the kinds of strains on the body were proportional to the increase of pulse frequency For instance increases of rectal temperature during the tests here described were not proportional to increases of pulse frequency, this fact meant a different value would be estimated from each form of strain,

TABLE 5 2 Interrelations Among Three Stresses When They Arouse Equal Increments of Heart Frequency*

Type of Stress	Stress A Equivalent	Stress B Equivalent	Stress C Equivalent
A Air temperature −32°		14 0 B	0 22 C
B Work rate	0 71 (A—32°)		0 16 C
C Bodily dehydration	4 5 (A—32°)	63 B	

* Units are those of Table 5 1

and indeed from equal stresses imposed on different men No general method has yet been devised for compounding concurrent strains, such as increment of pulse, increment of rectal temperature, and increment of arterial pressure, to yield a value that will accurately represent the overall resultant of many stresses

Here the example of pulse frequencies under additive stresses has been presented A parallel method has also been shown to yield satisfactory estimates of ventilation rates under additive stresses of high carbon dioxide, high altitude, and exercise (10) The method of comparing diverse stresses by means of their relative physiological effects is undoubtedly a general one, but actually quantitation of the effects is still limited to interpolations

Patterns of Regulations Regulations have been recognized for a great many components in addition to those mentioned above Not merely pulse frequency is reproducibly controlled, but also such components as body water content, body heat, sweat secretion, shivering, muscle tonus, and food intake Further, every living cell shows that controls exist of its chemical transformations, substance exchanges, and physical states For each physiological process whose details are investigated, there is found a multitude of factors that modulate the rate of the process Operation of most of these factors

appears to be built into the working constitution of the organism so that external circumstances rarely overpower the pattern of maintenance

What kinds of information have been found useful in understanding physiological regulations? How does someone design experiments to reveal their characteristics? Several types of regulatory patterns have been recognized (1) Often we can ascertain how speeds of activity vary with internal states of the body Thus an arterial pressure less than usual leads to reflex acceleration of heart and constriction of arterioles These "appropriate" responses raise the pressure by a graded amount By study of the gradations, that is, by quantitative comparison of responses with the physiological states (such as pressure change) which act as stimuli, the regulations can be described Any relation between rate and state may be here designated *type P*

Sometimes we can show that the concentration of a bodily constituent differs from the concentration outside (*type Q*) Thus carbon dioxide pressure in arterial blood systematically varies as the carbon dioxide pressure changes in the air breathed (Fig 5 3) Once we have worked out such a relation we have described the overall regulation, whether or not we know what bodily parts are implicated in ventilation, circulation, and blood manufacture

The constancy of a bodily property may itself measure regulation (*type R*) That body weight varies little from day to day or year to year speaks for a net control of all intakes and outputs of substance A measure of constancy, *such as standard deviation, tells us how unlikely large departures* from the mean or norm may be, and reflects the efficacy with which fluctuations are prevented Correlations likewise exist among diverse components whereby a change in one pulls another with it

In a separate category may be placed the varied behaviors that tend to preserve bodily constancies and controls (*type S*) Heat constancy is achieved not only by the devices for modifying heat gains and heat losses that are at work within the organ systems, but in the behaviors whereby more or less clothing is put on, or more or less exposure to fire or shade is chosen The preservative nature of such behaviors has been noted by observers in all ages of mankind, part of the task of modern physiology and psychology is to analyze their origins and their places in the constellation of regulatory activities

Finally, regulations are made up of processes and parts (*type T*) Contractions and muscles sensations and nerves, secretions and glands are the more obvious instruments of regulatory responses Actually, however, every living cell has its own self contained invisible regulatory activities, and the individual processes that fit together into the multiple patterns of its control are numerous indeed To unravel them requires tools other than anatomical ones it requires the use of biochemical inhibitors, imposed temperatures and all the armament of the experimenter

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These five types or patterns of relations that reveal regulations are certainly not the only ways in which relations important to regulatory study may be found But they are guides to future explorations They are types that have been worked out to date in studies of regulations

The general concept of regulations is a powerful one both in theory and in applications In theory we know how to find the pattern of a given regulation, since regulations of diverse components have been already analyzed and their usual conformations are known For instance, we recognize that we are to look for relations of type P between content or concentration of a property or component and its rate of change or exchange Only one content (the most usual one) allows complacency in which nothing is done to change it In application we are able to predict what sorts of compensations to expect, and predict that there will be limits to them Thus, we find there is on the average an upper limit to human heartbeat frequencies (about 210 beats per minute), and we can estimate from Table 5 1 what degree of dehydration and intensity of heat will impose this rapid heart rate without performance of any work at all We can further be sure that the recovery of heart frequency toward its resting value takes time, and that the recovery is faster after a great disturbance than after a small (Fig 5 2) Finally, we may, if we wish, attach an inference to the rate of recovery, and suppose that fast recovery is advantageous to the individual that has it Thus, upon comparing persons of diverse age we find that for pulse recovery there is a youth optimum (at 11 years, 3), and upon comparing persons with circulatory disturbances of diverse sorts we find that most have slow recoveries In other words the study of tolerances, equilibrations, and strains are the basis of fitness testing assessment of individual performance and evaluation of functional constitution

CONCLUSION

Regulatory physiology, the study of automatic controls in living phenomena, is viewed in terms of certain circulatory and respiratory responses to exercise and to recovery from it Frequency of heartbeat is found to be accurately graded in relation to intensity and duration of work Without necessarily complete information concerning the nerve impulses and mechanical and chemical factors of control, useful patterns have been established relating pulse frequency to steady and transitional states of exercise Breathing responses were similarly examined in relation to pressures of CO_2 and O maintained within the body Variabilities of functional properties and of behaviors that ease the tasks of internal controls were also noted Using an indicator of physiological strain such as pulse frequency, the relative stresses imposed on the body can be compared Altogether the regulatory patterns illustrated fell into five types which taken together describe the over all regulations inherent in physiological activities

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6 G N LOOFBOURROW

Neuromuscular Integration

SUMMARY

The coordinated operation of the skeletal musculature is one of the most obvious and most important of the body functions Man s ability to survive in a wide variety of environments and to adjust to drastic changes in his environment depends in large measure on his ability to direct his movements appropriately one has only to imagine how utterly dependent on others he would become in the event of complete paralysis to realize the truth of this statement

Skeletal muscles are completely dependent on the nervous system for their operation They remain relaxed and flaccid in the absence of signals from the central nervous system by way of motor nerve fibers These signals the nerve impulses are self-propagating waves of excitation Upon arrival at the motor end-plate of the muscle fiber they bring about changes leading to the generation of similar waves in the muscle cells themselves These self propagating excitation waves in muscle fibers are essential prerequisites for activating the contractile processes

Excitability and the process of excitation are basic characteristics of living matter When protoplasm loses its excitability and no longer undergoes excitation in response to stimulation, it is no longer recognized as living matter In most of our organs, excitation leads to a characteristic response For example when a skeletal muscle contracts, we recognize the shortening as the characteristic response of that kind of organ and infer that excitation must have occurred and served to trigger the response In the nervous system (central as well as peripheral), the situation is different in that the response of neurons is not a process which follows excitation rather, the response in neurons is the excitation process itself

Recent investigations have shed considerable light on the conditions essential to excitability and on the nature of the process of excitation In view

of this fact and of the obvious importance of an understanding of these basic matters to students of neuromuscular function, an effort has been made to present the essence of a considerable amount of painstaking (and often highly technical) research in concise, comprehensible language The aim is to explain the ionic hypothesis of excitability and excitation in terms which can be understood by individuals who do not have an extensive back ground in physics, chemistry and mathematics

The manner in which muscle contractions are quantitatively controlled from weak, barely noticeable contractions to very powerful ones is discussed in some detail and reconciled with the All or None Law

An evaluation of the electromyogram as a quantitative measure of con traction should prove useful to readers who have equipment for electro myographic recording at their disposal For others it should help in the critical reading of reports of experiments in which electromyograms were re corded Conditions in which the EMG does and does not provide a valid measure are discussed

In the section of this chapter on reflex control of the skeletal muscles, an effort is made to explain how the skeletal musculature is operated to provide responses which are qualitatively appropriate for the stimuli which evoke them The importance of the locus stimulated in determining the nature of the response is stressed

The classical concept of the stretch reflex and the operation of the muscle spindles has undergone much modification recently in light of studies of the small fiber motor nerve system to the spindles This and other fairly re cent contributions whose significance has possibly not been fully appreci ated are discussed One of these is the 'Renshaw feedback system whereby branches of active motor neurons conduct impulses back to synapse with 'Renshaw cells' in the cord The latter cells are interneurons which achieve synapse with active motoneurons and exert on them an inhibitory action By this means, motoneuron activity is somewhat self limiting

Finally, the parallel influence of the inhibitory and facilitatory areas of the brain stem reticular formation on the alpha motoneurons (to skeletal mus cle fibers) and gamma motoneurons (to intrafusal fibers in the muscle spindles) is considered Evidence is summarized to show that movement may frequently be initiated by having the gamma system serve as a sort of 'ignition mechanism" This is one of a number of instances which show that the central nervous system exerts a measure of control over the discharge of afferent impulses from receptors to the CNS This has been more ade quately studied for muscle spindles than for any other receptors

INTRODUCTION

The forces which move the supporting framework of the body are un leashed within skeletal muscles on receipt of signals by way of their motor

nerves. In the absence of such signals, the muscles normally are relaxed. Movement is almost always the result of the combined action of a group of muscles which pull in somewhat different directions, so the control of movement involves a distribution of signals within the central nervous system (CNS) to appropriate motor nerves with precise timing and in appropriate number. In order for movements to be useful in making adjustments to external situations, it is necessary for the central nervous system to be apprised of these situations which are continually changing. A means of providing this information promptly exists in a variety of receptors sensitive to changes in temperature, light, pressure, etc. These receptors are signal generators which dispatch signals (nerve impulses) to the CNS over afferent nerve fibers. The CNS receives these signals together with identical ones from within the muscles, joints, tendons and other body structures and is led thereby to generate and distribute in fantastically orderly array myriads of signals to various muscles. Thus despite the enormous complexity of the machinery involved, enables the individual to do one main thing at a time. This is integration. It is what Sir Charles Sherrington meant by "the integrative action of the nervous system" (37). We shall attempt to elucidate some of the mechanisms of integration.

THE MOTOR NERVE CONTROL OF SKELETAL MUSCLE

The Significance of Excitation

The vital motor nerve impulses referred to in the introduction are excitation waves which are generated in intraspinal portions of the motoneurons and are then propagated along their axons to the neuromuscular junctions within the skeletal muscles. As a result of the arrival of these impulses at the neuromuscular (N M) junctions there are generated excitation waves which are propagated through the muscle fibers in essentially the same manner as the nerve impulses through nerve fibers. This is *not the contractile* process but a conductile process entirely analogous to the propagation of the excitation wave in the nerve fiber. However, it is a prerequisite to contraction in physiological circumstances and is responsible for initiating those biochemical reactions whose end result is contraction.

It is important that to develop a clear concept of the process of excitation before beginning the study of neuromuscular integration. Excitation is a self propagating signal which flows rapidly from the motor end plate through all parts of the muscle fiber and triggers the contractile mechanism. It is also a self propagating signal which passes from centers in the spinal cord along motoneuron fibers to their terminations at N M junctions within skeletal muscles, as well as a self propagating signal that passes from receptors along afferent fibers to the central nervous system. It is the very keystone of neuromuscular integration.

THE IONIC BASIS FOR EXCITABILITY THE RESTING MEMBRANE POTENTIAL

Excitation is a process involving complex physical and chemical changes, including movements of electrically charged ions In this section we shall consider the ionic and electrical situation in the resting cell as a background for a discussion in the next section of the changes which take place during excitation

The membrane of an excitable cell is polarized, the exterior being positively charged with respect to the interior This potential difference is associated with an unequal distribution of ions on the two sides of the membrane of the resting cell

There seem to be two major reasons for the unequal distribution of ions (1) Synthesis within the cell of organic anions to which the cell membrane is impermeable, (2) active extrusion of Na^+ ions (cations) These two factors would tend to make the interior of the cell negative with respect to the exterior As a result of this tendency, diffusible anions (chiefly Cl^-) are repelled by the negative charge inside the cell and are attracted by the positive charge outside One would therefore expect (and find) Cl^- ions in greater concentration outside than inside the resting cell Moreover, the concentration ratio of Cl^- outside to Cl^- inside should be just enough so that the tendency for the outward diffusion of chloride ions due to the electrical gradient would be exactly equalled by a tendency for inward diffusion due to their concentration gradient Thus, at equilibrium, outward and inward diffusion of chloride ions would be equal and their net exchange zero Similarly, diffusible cations (chiefly K^+) would be expected to reach equilibrium when the ratio of K^+ inside to K^+ outside is adequate to balance the electrical gradient which tends to force them inward [1]

On the basis of the concept of ionic equilibrium outlined in the preceding paragraph, Nernst developed an equation relating the ratio of internal to external concentration of a diffusible ion to the value of the electrical potential across the resting membrane If the concentration gradient of an ion is known, it should be possible to calculate the electrical gradient against which it is balanced This electrical gradient would be the resting membrane potential, E_r In its simplest form the Nernst equation for E_r at room temperature may be stated as follows

$$E_r \text{ (in mv)} = 58 \log_{10} \frac{(K^+)i}{(K^+)o}$$

$$\text{or} \quad E_r \text{ (in mv)} = 58 \log_{10} \frac{(Cl^-)o}{(Cl^-)i}$$

Actual measurements of E_r prove to be almost exactly that calculated by the Nernst equation from measured values for chloride ion concentrations

[1] On thermodynamic principles Donnan developed a theory to account for the unequal distribution of diffusible ions in the presence of a nondiffusible ion This is now widely accepted as the Donnan theory of membrane equilibrium Textbooks of physical chemistry may be consulted for details

Similar calculations based on the potassium ion concentrations usually indicate a slightly lower L_r than is actually found by measurement Since the discrepancy is not great it has been attributed to experimental error, but Eccles (7) suggests that it is a real discrepancy due to the presence of an additional factor which aids the electrical gradient in holding K^+ ions inside the cell against their concentration gradient This additional force need not be large for the electrical gradient is almost adequate to balance the force of outward diffusion resulting from the high ratio of internal to external potassium ions (20 to 50 1) Eccles postulates an active biochemical process referred to as a *potassium pump* to supply the small additional inward force required

If the cell membrane were freely permeable to sodium ions, the resting membrane potential required to maintain the (approximate) 10 1 external to internal ratio of sodium ion concentrations found experimentally would have to be about 50 mv *positive inside* with respect to the outside All experimental evidence shows the interior to be *negative* (ca 70 mv) Therefore the electrical gradient, instead of opposing the concentration gradient as it does in the case of K^+ and Cl^- ions, is in the same direction There has to be a mechanism which extrudes sodium against a steep inward diffusion gradient consisting of the combined electrical and concentration gradients A *sodium pump* is postulated for this, operating by an active biochemical process analogous to that of the potassium pump mentioned earlier But the need for a sodium pump is much greater and became evident earlier than the need for a potassium pump Correspondingly, the literature is replete with references to the sodium pump, while relatively little is said about the potassium pump Little is known of the actual nature of either of these hypothetical pumps Presumably the operation of the sodium pump is regulated by the internal sodium concentration in such a way as to maintain the 10 1 external to internal concentration ratio despite the combined electrical and chemical gradients tending to force sodium ions inward The original ionic hypothesis proposed by Bernstein in 1902 (1) did not include this concept The modern ionic hypothesis was formulated by Hodgkin and Katz in 1949 (22)
graphs by Ec
as it pertains
tential Since the sodium pump is by far the most important factor in maintaining an unequal distribution of ions, it is really the mechanism ultimately responsible for the resting membrane potential This was postulated in 1954 (15) and is now an accepted part of the ionic hypothesis

EXCITATION AND THE IONIC HYPOTHESIS

the surface membrane of a motoneuron Metabolic activities of the cell keep the battery charged to around 70 mv, the inner surface being the negative pole and the outer surface the positive pole The resistance of the membrane, which is high in the resting cell, falls during excitation, permitting discharge of the "capacitor

The electrical properties of neurons are so striking that for a number of years consideration of electrical phenomena largely obscured the fact that in the intra and extracellular body fluids, electric currents are conducted by electrolytes, i e, by the movement of ions Intensive work during the past few years however (particularly that by Hodgkin and his associates, cited in the preceding section) has emphasized the significance of ions in the electrical phenomena including the action potential and action current

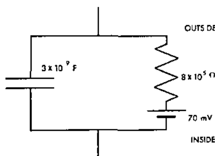


Fig 6 1 *Formal electrical diagram of the resting membrane of a standard motoneuron showing mean values for the membrane potential, capacitance, and resistance* (Eccles, 7)

Whether or not one is thinking in terms of ion movements, the concept of excitation in terms essentially of the discharge of energy stored as a resting membrane potential is inadequate It appeared to be a satisfactory explanation as long as measurements of potential were made exclusively through extracellular electrodes Such measurements always showed the action potential, i e, the change in the membrane potential during activity, to be less than the resting potential After the introduction of microelectrodes, however, it soon became apparent that when the action potential was measured directly across the membrane with an intracellular and an extracellular electrode, the change during activity often exceeded the preexisting potential This indicates not a simple discharge which, at best, could only reduce the membrane potential from its resting value to zero It indicates a process by which the resting membrane potential is reversed, becoming during excitation internally positive and externally negative Recent studies (6) using a microelectrode inserted inside a motoneuron in the ventral gray column of a cat s spinal cord reveal a resting potential of 70 mv (internally negative) and an action potential of 120 mv (internally positive)

The "overshoot of the spike potential (i e, the reversal of resting potential during excitation) is accounted for by the modern ionic hypothesis According to this hypothesis, the stimulus brings about a sudden, drastic increase in membrane permeability As a consequence, sodium ions commence to flow inward along their steep electrochemical gradient This leads to activation of a biochemical mechanism which actively forces Na^+ ions in Thus depolarization begins by passive inward diffusion of Na^+ ions and is

enhanced by active transfer through operation of a sodium carrier system (note that the sodium pump is a system for active *outward* transport of sodium ions, whereas the sodium carrier is a system for active *inward* trans port) Through the combined passive and active influx of Na^+ ions, enough positive charge accumulates inside to reverse the resting potential This inward movement of sodium ions thus produces the spike Classically, the spike is a negative deflection but it should be clear that it is negative only when measured by an electrode placed outside the cell An intracellular electrode records the spike as a positive deflection

Only the first, or 'rising,' limb of the spike potential is accounted for by sodium ion inflow The descending limb, indicating restoration of the resting potential, requires the outflow of a like number of ions of like charge Immediate recovery of excitability is not accomplished by the ejection of sodium ions—no mechanism is available which can do this within the millisecond (approximately) before the neuron can be excited again In stead, it is accomplished by the outflow of potassium ions This outflow actually begins early during the *rising* limb of the spike when incoming sodium ions disturb the dynamic equilibrium Potassium outflow begins as passive diffusion along its concentration gradient It is thought that a potassium carrier system is activated and aids the outflow Of course when the membrane is excited and its potential is reversed, the internal positivity would also aid in expelling K^+ ions During the rising limb of the spike, *sodium inflow* begins slowly, accelerates tremendously, then begins to slow down as the carrier system s activity wanes During this same time, *potas sium outflow* is accelerating Suddenly the outflow becomes dominant and the spike ceases to rise and starts to fall The process of restoration of the resting potential has overtaken the processes responsible for the spike

Excitation, then, is recognized by an action potential spike of about a millisecond in duration The variation in membrane potential which we call the spike is accomplished by trading sodium for potassium ions across the cell membrane sodium inflow leading and causing the rising limb of the spike, potassium outflow promptly following and restoring the resting potential Only a tiny fraction of the available Na^+ and K^+ ions are ex changed during a single impulse, so that many thousands of impulses would not seriously affect their respective internal and external concentrations Moreover, the sodium pump, while not fast enough to eject sodium ions for recovery of excitability within a millisecond, as potassium outflow can, operates continuously and replaces the external potassium by sodium during the neuron's inactive periods

Conduction and Transmission

Conduction refers to the propagation of excitation along a nerve fiber The nerve fiber is commonly represented by a diagram as in Fig 6 2A The charged membrane is indicated by plus and minus signs The excited region

in older diagrams is represented as simply depolarized, i e, the plus and minus signs are absent from the excited regions The figure shown here represents the excited region as a region of reversed potential in accord with evidence now available It goes a step further, however and indicates by means of arrows the inflow of sodium ions during the rising phase of an

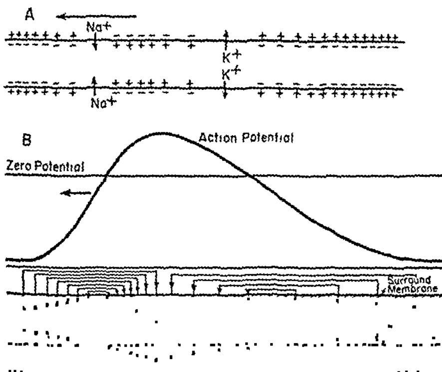


FIG 6 2 A *Diagram showing postulated movement of sodium and potassium*

while lower part shows the resulting flow of electric current both in the external

approximately the same position as in A (Eccles, 6)

advancing spike Similarly, K ions are indicated as moving outward during the declining phase of the receding spike This should help to combat the impression so often left by classical diagrams that the plus and minus signs represent disembodied' electrical charges rather than the charged ions which actually are responsible for the membrane potential of both the resting and active cell

Propagation in the classical diagram is usually represented by arrows indi

cating local electrical currents passing inward through the excited region and outward through adjacent regions as in the lower part of Fig 6 2B This current outflow through adjacent regions is said to be the stimulus which serves to increase membrane permeability, leading to excitation there, and so on down the fiber On the basis of the information we now possess about ionic transfer in excitation a simple and useful concept would seem to be as follows the stimulus increases permeability of the membrane; the excited region becomes a sink into which sodium ions flow, sodium ions from adjacent, nonexcited regions flow toward the sodium depleted region, thereby partially depolarizing the adjacent regions partial depolarization leads to increased permeability and activation of the sodium carrier system of the adjacent regions so sodium inflow begins there and these regions become excited Thus excitation is propagated If the stimulus is applied at the center of a long fiber, the excitation wave proceeds toward both ends followed by restoration which also begins in the center and proceeds toward the ends Fibers conduct equally well in either direction

Propagation of excitation across protoplasmic discontinuities is quite a different process from conduction along a nerve fiber or a muscle fiber One very important difference is that transmission can take place in one direction only Synapses and neuromuscular junctions are one-way valves' in the pathways over which excitation is propagated Propagation across such junctional regions is usually called transmission instead of conduction It has been most fully investigated at neuromuscular junctions and at the synapses in autonomic ganglia The nerve impulse in a motoneuron is conducted only to the neuron terminals If it is to lead to muscular contraction it must in some way serve as a stimulus which arouses a new excitation wave in the muscle cell innervated by each of its terminals (One motor nerve fiber may have up to a hundred or more branches to a like number of muscle cells Each motoneuron, together with the muscle cells it innervates, constitutes a motor unit) Normally, every time a nerve impulse in one of the terminal branches of a motoneuron reaches the neuromuscular junction, it serves as a more than adequate stimulus and evokes excitation of the muscle cell One muscle impulse is aroused as the response to the arrival of the nerve impulse at the neuromuscular junction The muscle impulse is a self propagated wave of excitation which is conducted from the motor end plate (neuromuscular junction) throughout the length of the muscle fiber

Neuromuscular and synaptic transmission means, then, the excitation of postjunctional cells in response to the arrival of nerve impulses at the terminals of prejunctional axons The excitation process in the postjunctional cell is the same ionic electrical process described earlier and is all or none in character That is the amplitude of the spike potential in the postjunctional cell is independent of the amplitude of the spike in the prejunctional cell

Although a single impulse arriving at one neuromuscular junction is usually more than adequate to excite the muscle fiber, this is not the case at cen

tral synapses The usual requisite for excitation of a neuron in the CNS is the virtually simultaneous arrival of a number of impulses at different excitatory end knobs synapsing with the neuron s soma and dendrites Another requisite is that there must not be impulses arriving at too many inhibitory end knobs at the same time, or else the excitatory effects would be nullified Within the CNS, therefore, whether or not a neuron is excited is determined by the algebraic sum of the effects of impulses arriving at excitatory and inhibitory terminals (end knobs) in synaptic contact with it This is what is implied in the term *central summation*

How does the prejunctional impulse stimulate the postjunctional cell to generate its impulse? Search for the answer to this question has been intensive for many years It is now generally agreed that at the neuromuscular junction (and at autonomic synapses) a chemical substance, acetylcholine (hereafter ACh) is required for transmission Most investigators subscribe to the *neurohumoral theory* of transmission at these junctions according to which a bit of ACh is released at each prejunctional terminal upon the arrival there of the nerve impulse Almost instantaneously the ACh is presumed to diffuse across the exceedingly narrow junctional gap and serve as a chemical stimulus to the postjunctional cell This would mean that the ACh serves to increase the permeability of the cell membrane allowing the initial inflow of sodium ions by which excitation is begun, as described earlier Nachmansohn (35) suggests that ACh increases the permeability of the membrane by temporarily combining with a receptor substance whose molecular configuration is thereby altered The ACh receptor substance combination would be very short lived because of the presence of an abundance of ACh destroying enzyme, acetylcholinesterase, in the junctional region The combination molecules would break down and give up ACh molecules as rapidly as the esterase destroyed them Thus membrane permeability would again be reduced and the membrane potential could be restored to its resting level

It is generally supposed that analogous processes account for synaptic transmission in the CNS There would have to be an inhibitory transmitter as well as an excitatory one Very probably there is more than one excitatory chemical substance and also more than one inhibitory substance Much work remains to be done in this area

The Graded Twitch and the All or None Law

Few experimental preparations have been used more widely in student laboratories of physiology than the nerve muscle preparation The gastrocnemius muscle of the frog with its motor nerve is favored because of its rugged dependability By simply recording the contractions with a muscle lever writing on a smoked drum one may demonstrate many of the classical features of nerve muscle physiology It may readily be shown that a single stimulus applied to the motor nerve results in a single, brief twitch By care

fully varying the strength of stimulus it may be shown that within a certain range of voltages the twitch height (the extent of contraction against a given load) varies directly with the strength of stimulus One may run the entire gamut of stimulus strengths from those which are too weak to cause a visible contraction (subminimal) to minimal or threshold (the weakest stimulus causing a visible response), then through a series in which the contraction increases with the stimulus (submaximal) As the experimenter continues to increase the strength of the stimulus, he eventually reaches a point beyond which further increments fail to produce a corresponding increase in con traction When the contraction reaches this plateau, it is said to be maximal and the weakest stimulus which produces a maximal contraction is a maxi mal stimulus Stronger stimuli are called supramaximal, indicating that they are stronger than needed to evoke a maximal response

We have noted that within a given range (submaximal) of stimulus in tensities, the strength of response of skeletal muscle varies directly with strength of stimulus but that in the supramaximal range there is no relation between them Bowditch reported in 1871 that the nerve free apex of the frog ventricle showed strength of stimulus to have a complete lack of any influence on strength of contraction Bowditch's original statement of the all or none relation is translated as follows An induction shock produces a contraction or fails to do so according to its strength if it does so at all it produces the greatest contraction that can be produced by any strength of stimulus in the condition of the muscle at that time ' It is clear that a skele tal muscle obeys the All-or None Law if stimuli are supramaximal but does not obey it if stimuli are submaximal How can this paradox be reconciled?

The intriguing history of the All-or None Law cannot be told here but it has come to be regarded a

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duced responses increasing in stepwise fashion Increasing the strength of stimulus did not increase the size of the twitch until it reached threshold strength for an additional fiber Each fiber, when it contracted, did so with a force which was independent of the strength of stimulus

After the development of techniques for work with single muscle fibers, it became clear that except under very special circumstances the contraction of a single muscle cell was all-or none However, graded contractions in single muscle cells are possible, provided the stimulus is so restricted to a small enough area and a low enough intensity that a propagated excitation wave is not produced (11,12) The crucial experiments of Brown and Sichel (2) demonstrated that the contractile process itself operates in complete disregard of the All or None Law By use of massive stimulating electrodes the stimulating current could be applied to all parts of an individual muscle cell simultaneously In this circumstance the muscle cell, freed from its de

pendence upon the normal propagated excitation wave, was found to produce contractions whose strength varied directly with the strength of the stimulus It is now clear therefore that the contractile process itself is not independent *of the size of the stimulus and does not obey the All-or None* Law although under normal circumstances it appears to do so because it is the consequence of an excitation process which is all or none

It is not difficult to reconcile the All or None Law with the phenomenon of the graded twitch when it is recognized that, as the strength of stimulus applied to a muscle or to its motor nerve is increased, the threshold of an increasing number of fibers is reached and each contributes its own independent quota to the total response as a result of its excitation The activation of an increasing number of units in this way is spoken of as recruitment

A skeletal muscle, as a general rule, contains many more muscle fibers than there are efferent fibers in its motor nerve Each motoneuron branches and innervates many muscle fibers One motoneuron, together with the muscle fibers it innervates, is a *motor unit* Clark (3) found 100–160 muscle fibers in the average motor unit of mammalian limb muscles Early investigators (4) determined maximal twitch tension for an entire skeletal muscle, divided it by the number of efferent fibers in its motor nerve, and arrived at a figure for maximal twitch tension for an individual unit

Two sources of error are now recognized in this procedure It was discovered in 1945 that roughly a third of the efferent fibers do not contribute to the contraction of the muscle through its tendon (26) These are the small gamma fibers, which are found to innervate the intrafusal fibers of muscle spindles and regulate the generation of afferent signals by the spindle receptors This will be discussed more fully later Another source of error was revealed by histological (10) and physiological (24) evidence that in many cases a single extrafusal muscle fiber has several motor endings belonging to different large fiber motoneurons Both these facts—(1) the number of motor nerve fibers innervating extrafusal muscle fibers is smaller than formerly supposed, and (2) an extrafusal muscle fiber may be a part of several motor units—indicate that the motor unit contains more muscle cells than was realized in Sherrington's time and that the figures which he and his co workers gave for the tension contributed by a single motor unit are too small[2] As a result of the overlapping innervation (*convergence of several* motoneurons on the same muscle fibers), the maximal twitch tension for the whole muscle would be less than the sum of tensions of the twitches of all the units responding individually Conversely, a single motor unit would be capable of more tension than one would calculate by dividing maximal tension of the entire muscle by the number of motor units in it

[2] Eccles and Sherrington (8) gave the following figures for maximal tetanus tensions for motor units in several cat muscles gastrocnemius medial head 30 1 grams soleus 9 9 grams extensor digitorum longus 8 6 grams and *semitendinosus* 5 5 grams

TETANUS

Repetitive stimuli lead to a series of twitches if the repetition rate is low and to partially or completely sustained contractions as the frequency is increased Such contractions are called *partial or complete tetani* The tensions developed in these situations exceed those developed in single twitches and most authors have used the values given by the Sherrington group (4) who stated that maximal tetanic tensions might be up to about four times maximal twitch tensions This phenomenon is referred to as *wave summation* or the *summation of contractions* The frequency required for complete tetanus differs from one muscle to another being in the cat about 30 per sec for the soleus 100 per sec for the gastrocnemius and 350 per sec for the internal rectus These figures vary considerably with conditions altering the speed at which the muscle shortens and relaxes and the rate at which excitability is recovered For example in fatigue all these activities are retarded and complete tetanus is possible at much lower frequencies

In physiological conditions the impulses reaching a muscle through its many motoneurons are out of phase or asynchronous Since the muscle may contain hundreds of motor units the pull on its tendon is likely to be sustained even though individual muscle cells are contracting with twitches or partial tetani It is probable that complete tetanus of a muscle fiber occurs infrequently if at all in human muscles in view of the fact that the frequency of excitation in the human biceps has been shown to fall within a range of 5 30 per sec in most cases and to reach only 50 per sec with maximum voluntary effort (27)

The total tension exerted by a muscle on its tendon at any instant is the sum of the tensions exerted by the active muscle fibers at that instant (*multifiber summation*) All factors which increase the likelihood for many units to be exerting tension simultaneously will contribute toward an increase in total tension For example an increase in frequency of excitation even when it is insufficient to lead to complete or partial tetanization of muscle fibers increases the chance for the random twitches of different units to be superimposed an increase in frequency sufficient to tetanize some of the fibers provides still greater assurance of multifiber summation

THE ELECTROMYOGRAM AS A QUANTITATIVE MEASURE OF CONTRACTION

The electromyogram (EMG in subsequent references) is a record of the electrical events associated with excitation In view of the evidence which indicates the separability of the processes of excitation from those of contraction it must be concluded that information concerning contraction may be derived from the EMG only by inference There is considerable experimental basis however for assuming that when the muscular response is a result of activity of the CNS (reflex voluntary or by direct cortical stimulation) the EMG amplitude parallels the amplitude of the mechanical

response (13,25,28) In all these physiological situations the timing of impulses in the various motoneurons is random and the factors which determine the chance for summation of the action potentials also determine the chance for the summation of contractile responses (multifiber summation) These factors are two (1) the number of units excited (extent of recruitment), and (2) the frequency of excitation of individual units

With experimental stimulation of the motor nerve the situation is different The muscle fibers of the various active units contract *in phase* and the only situation in which alterations in strength of stimulus and strength of contraction run parallel is one in which strength of stimulus is varied in the submaximal range and all other factors remain constant In this circumstance the number of motor units activated varies directly with stimulus strength, therefore both the summed action potential (of either the nerve or the muscle) and the summed contraction likewise vary directly with the intensity of stimulus If a supramaximal stimulus of constant amplitude be used, so that the number of units excited remains constant the amplitude of the EMG will remain essentially constant too, even though the mechanical response may vary considerably with different stimulus frequencies, different loads, or different initial lengths It must be assumed that in these conditions, it is the contractile process rather than excitation which varies and since the EMG is a direct indicator of excitation rather than of contraction, it fails in these specific nonphysiological situations to provide a reliable measure of contraction (32)

In fatigue, the EMG may or may not diminish in amplitude as the contraction weakens At quite low stimulus frequencies the mechanical response may diminish while the EMG remains constant whereas at higher frequencies the EMG amplitude and contraction amplitude decline together This difference is based on the fact that with higher frequencies a reduction in the number of contracting muscle fibers occurs due to fatigue of the neuromuscular junction while with sufficiently low frequencies it is possible to fatigue the contractile mechanism alone Failure of neuromuscular transmission will of course reduce the number of muscle fibers *excited* hence reducing EMG amplitude and, since those which are not excited will not contract, the mechanical response will also be less With a low stimulus frequency, transmission may be unaffected so the number of muscle fibers excited and the EMG remain unchanged, although in time the contractile process shows evidence of fatigue in a diminished mechanical response (32 5)

It should be emphasized that although the EMG is only an indirect measure of contraction, and although it is possible to set up conditions in which the mechanical and electrical responses appear unrelated, *in physiological conditions, EMG amplitude and the mechanical response are essentially parallel*

REFLEX CONTROL OF THE SKELETAL MUSCLES

THE SIGNIFICANCE OF REFLEX ACTION

Most, if not all, neural control of skeletal muscles is *reflex in nature* Ordinarily we think of a reflex as the contraction of a muscle in response to nerve impulses relayed from receptors to the muscle through a reflex arc consisting of afferent and efferent neurons, with interneurons of the CNS between them in most cases This is somewhat misleading, however, for the afferent signals may just as well result in the reduction or cessation of contraction Such reflex inhibition is not the result of impulses traversing the entire reflex arc but is due to a reduction of the excitability of motoneurons by the influence of impulses reaching them at central synapses If inhibition is complete, the efferent limb of the reflex arc simply is not operating, yet we speak of reflex inhibition in such a case It is better, therefore, to think of reflex regulation of the musculature in terms of the increase or decrease of excitability of motoneurons resulting from impulses reaching them from afferent neurons either directly or through interneuronal relays

How about voluntary movement? Is this not also the result of the influence of impulses impinging on motoneurons after relay from afferent neurons through interneuronal circuits which in this case include cortical neurons? Certainly this would appear to be true It would involve greater delay, it would allow for modification of the response on the basis of information from all kinds of receptors, since the cortex receives signals from all kinds, it would permit modification of the response on the basis of information received from receptors as the result of *past* experiences, since the cortex can store information Thus it would provide opportunity to act intelligently in the light of both past and present experience and with action we would call voluntary And yet, is it not of the nature of reflex action? Again it would seem so, and whether we actually call the integrated response a reflex or not would appear ultimately to depend upon whether or not we can say the will directed it If we can say it did then we shall call it a voluntary act If we cannot say it was voluntary then we may call it a reflex, no matter how complex the circuits or how purposive the response In either case the fundamental mechanics of the processes are the same, which is what we meant in the first sentence of this section when we said, Most, if not all neural control of skeletal muscle is *reflex in nature* "

In this section we shall limit our attention to spinal reflexes, one of which operates without the need of interneurons and others of which involve interneurons within the spinal cord We shall see, however, that even those reflexes whose basic arcs are restricted to only a few contiguous segments of the spinal cord are strongly influenced by circuits involving supraspinal interneurons within the brain stem reticular formation This influence is so important that, although the so called spinal reflexes can ultimately be

obtained in its absence, they are radically weakened or abolished for a considerable time after its loss, as in the case of spinal transection

LOCAL SIGN AND ITS SIGNIFICANCE

Cutaneous Receptors

Sherrington (37) stated in 1906 that 'The *locus* of a stimulus plays an important part in determining the nature of the reflex involved The influence of the location of the stimulus on the resulting reflex movement has been one of the features most studied in reflex action It furnishes a large part of the purposive character of spinal reflexes" The scratch reflex may be used as an example In the spinal dog, appropriate stimulation of the skin in the shoulder region elicits rhythmic scratching movements of the hind leg whose direction and coordination appear "designed' to remove the irritating stimulus It would seem that the rather large skin area from which the reflex may be evoked corresponds with the skin area which can be reached by the paw Thus the *local sign* is an indication of intimate central connections between the receptors of a specific region and the effectors whose operation can control the environmental changes playing upon them

Large nerve trunks usually contain afferents from receptors of many sorts which are scattered over such a large area that reflex movements evoked by their stimulation cannot reveal a clear cut local sign So many of the reflex experiments carried out during the first half of this century involved such "whole nerve" stimulation that the relation between receptor location and the pattern of muscular activity evoked was largely obscured It is a reasonably safe prediction that stimulation of a large afferent nerve trunk in a limb will lead to reflex flexion of the same limb and may also elicit extension of the contralateral limb In fact, the student frequently is led to suppose that

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ciate, the crossed extensor reflex This, however, is definitely not the case

Occasional references in the literature, including the early work of Sherrington and his collaborators, indicate a more discrete organization than this and show that stimulation of certain small afferent nerves may lead to *ipsilateral extension but it remained for Hagbarth (16) to provide a much* needed clarifying analysis He demonstrated a direct functional connection between a muscle and the area of skin which covers it In brief, he found that pinching the skin of the hind limb of the cat evokes a reflex contraction of the underlying muscle, whether it be a flexor or an extensor, with relaxation of its antagonist

Local sign in spinal reflexes illustrates a cardinal principle of neural organization The *location* of the excited receptors plays an important part in the

selection of the *effectors* which will consummate the reflex act It follows that location of receptors is an important factor in determining which moto-*neurons* will be excited and/or inhibited This principle has much more general application Textbooks of physiology and anatomy contain cortical maps

mechanisms, therefore, we find evidence of local sign, and although the term itself is not often found in current literature, the localization of function which it represents is established beyond question at all levels of the nervous system Were this not true, neurosurgery would often be worse than useless

Proprioceptors

The importance of the location of receptors in determining the distribution of their reflex effects has long been known in the case of proprioceptors For example, Lloyd (31) states that "one important feature of the stretch reflex, no matter in what muscle it may be elicited, is its intensely restricted field of action A stretch reflex response appears only in a muscle subjected to stretch, other muscles being unaffected or inhibited Indeed, traction on one head of a muscle provokes a reflex only in that head of the muscle, the others remaining quiescent ' Recent evidence, which will be briefly discussed in the next section, shows that the receptors which are activated by stretch of a muscle exert a much more widespread influence than the above statement would lead one to expect The fact remains, however, that the motoneurons of the stretched muscle are usually more potently affected than any other motoneurons[3] because they lie in the best position to receive impulses via afferent fibers from stretch receptors located in that muscle Moreover, it is the anatomical distribution within the spinal cord of afferent fibers from the particular muscle which is stretched that determines the distribution of reflex influence extending *beyond* the stretched muscle

THE CLASSICAL STRETCH REFLEX

Autogenetic Facilitation

Sherrington and his co-workers recognized early that support of the body against the pull of gravity begins with stretch reflex activity originating within the antigravity muscles As soon as the legs begin to buckle, the extensor muscles are stretched, exciting stretch receptors within them The resulting impulses are conducted to the spinal cord over afferent fibers which

[3] This is true for extensor (antigravity) muscles, but stretch of a flexor muscle leads to an inhibition of the antagonistic extensor which is more prominent than the reflex contraction of the flexor

make synaptic connection directly with motoneurons of the muscle containing the excited stretch receptors They excite or increase the excitability of (facilitate) these neurons Since no interneuron relay is required, this neural connection between receptor and effector is referred to as a *monosynaptic reflex arc* The stretch reflex is the only reflex known to be mediated through a monosynaptic arc

Reciprocal Inhibition of Antagonists

In addition to autogenetic facilitation (i e, facilitation of motoneurons of the muscle stretched), there is inhibition of the antagonist of the stretched muscle On the basis of similar latencies, Lloyd (29) concluded that this reciprocal inhibition was also mediated by monosynaptic arcs This has recently been questioned by Eccles (6) who believes that the large afferent fibers from the muscle spindles (stretch receptors) exert purely excitatory effects in spinal centers He presents evidence which indicates that the inhibition of motoneurons of an antagonist of the stretched muscle is mediated by specific inhibitory interneurons He believes that the primary afferent fibers from the stretch receptor excite not only motoneurons of the stretched muscle but also interneurons which terminate synaptically on antagonistic motoneurons, where they exert an inhibitory influence Eccles assumes, in common with most physiologists today, that every neuron of the nervous system may be classed as either an excitor or an inhibitor, depending upon whether its synaptic end knobs release an excitor substance or an inhibitor substance upon the arrival of a nerve impulse Synaptic transmission of both excitatory and inhibitory effects is thus conceived to depend upon transfer of chemical substances across the synaptic space

The Muscle Spindle

The receptor organ responsible for the classical stretch reflex described above is the muscle spindle It is an elongated, fusiform capsule containing several striated intrafusal muscle fibers (six in the cat s soleus muscle) The structural features of an intrafusal fiber are shown in Fig 6 3 For the present we shall ignore the consequences of their contractility which is not required in order for the spindle to serve as a stretch receptor Our concern at present is with the ending of a large afferent nerve fiber[4] entwined around the middle of an intrafusal fiber, a region which is nonstriated and noncontractile Because of its appearance, it has been called an *annulospiral ending* It is also known as a *nuclear bag ending* since the lymph filled capsule surrounding it is designated the *nuclear bag* Other names for them are *A_2 endings* (34) and *primary endings* These are the endings responsible for the classical "stretch reflex," i e, reflex contraction of the muscle stretched and inhibition of its antagonists

[4] These are among the largest of mammalian nerve fibers with diameters up to about 20 microns

Between the nonstriated nuclear bag portion of the intrafusal fiber and the striated polar regions lies a transitional myotube region This may or may not possess afferent innervation When present, it is best called a *myotube ending* Matthews (34) referred to it as an A_1 ending Other

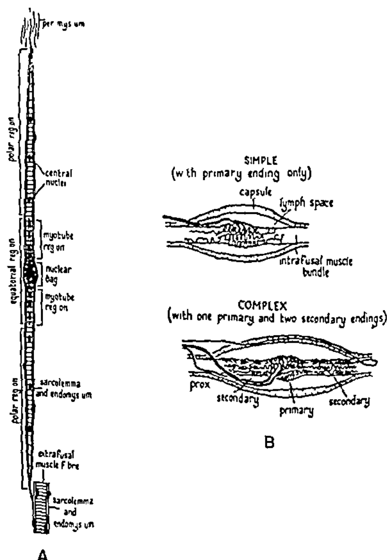


FIG 6 3 A *Diagram of a single intrafusal muscle fiber, each polar region has been shortened to about a third of its typical length* B *Diagrams of the equatorial regions of two rabbit muscle spindles illustrating types of sensory innervation Intrafusal muscle bundle shown in outline only, and area of nuclear bags indicated by exaggerated swelling Spindle from m vastus intermedius of quadriceps Single and complex ending shown* (Barker, Quart J micr Sci, 1948, 89, 143)

synonyms are *secondary ending* and *flower spray ending* Its significance is largely unknown

The muscle spindles are excited when the muscle is stretched When the muscle shortens it should relieve the spindle of tension, or "unload' it, since it lies parallel with the muscle fibers Matthews (34) demonstrated by recording action potentials from single spindles that the continuous repetitive spindle discharge of a spindle in a slightly stretched muscle does indeed cease when the muscle contracts This pause, however, is transient By a mechanism to be described later, the contractile polar regions of the intrafusal muscle fibers are caused to contract and they shorten sufficiently to restore the tension on the nuclear bag regions, thus "resetting' the spindle to register tension at the new, shorter muscle length

The Myotatic Unit

Lloyd (30) suggested the term *myotatic unit* for the group of muscles of a given joint which are linked by myotatic, or stretch reflexes Stretch leads to facilitation of the synergists of the stretched muscle and inhibition of their antagonists It was then believed that the spindle afferents made monosynaptic connections with both motoneurons of their own muscle, which they facilitated, and with the motoneurons of its antagonist, which they inhibited Serious doubt has been cast on the monosynaptic nature of the reciprocal connections of the spindle afferents (6) It has also been demonstrated that stretch of a muscle may evoke contraction of other muscles acting at a *different* joint in the same limb (33) Moreover stretch which excites the tendon organs of an extensor muscle may evoke, in addition to the autogenetic inhibition and facilitation of the antagonistic flexor, *contralateral* extensor contraction (Phillipson's reflex) In view of the complex, widespread reflex effects of muscle stretch (14), only a few of which have been discussed here, it must be recognized that the myotatic unit, as defined, is only an arbitrary fraction of the structures influenced by the stretch of a muscle

Autogenetic Inhibition and the Golgi Tendon Organs

Stretch can lead to self inhibition, as well as to self-excitation Since inhibition is the reduction or elimination of activity it can only be observed on a background of activity Transection of the brain stem rostral to the vestibular nuclei and just caudal to the red nucleus (decerebration) provides an animal whose muscles show such vigorous continuous activity that the condition is called *decerebrate rigidity* This provides an excellent preparation for demonstrating inhibition

If forcible attempts are made to flex a limb joint which is maximally extended in decerebrate rigidity, powerful resistance is encountered In order to flex the joint, the extensors must be stretched In addition to the strong, continuous extensor contraction in the decerebrate animal, the stretch receptors are in a hypersensitive condition, so they oppose stretch of the

muscle in proportion to the force applied If the force is maintained, however, the muscle will suddenly 'let go' and lengthen i e, the resistance suddenly collapses This is Sherrington s *lengthening reaction*, which has also been called the *clasp knife* phenomenon

The Golgi tendon organs are the receptors responsible for this autogenetic inhibition of motoneurons If one tries to flex the rigidly extended joint by applying a gentle force, then slowly increasing it, the first effect will be actually to increase the contractile tension of the muscle (stretch reflex) Only when considerable force is applied will the tension increase sufficiently to excite the high threshold Golgi tendon organs When sufficiently excited, however, they are capable of so reducing the excitability of motoneurons of the muscle that relaxation occurs despite the most intense excitatory influences This is a protective measure, reducing the chance of damage to the muscle or its tendinous attachments from excessive tension

Unlike the spindles, the Golgi tendon organs are *in series* with the muscle fibers Passive stretch puts both spindles and tendon organs under tension The sensitive spindles respond to all degrees of tension, even slight The higher threshold Golgi tendon organs respond when the tendon is placed under moderately high or severe tension Active contraction, too, puts the tendon under tension and the tendon organs respond, whereas the spindles are 'unloaded so their firing slows or stops The inhibition of an extensor by discharges from the Golgi organs in its tendon is accompanied by facilitation of its flexor antagonist

The Renshaw Feedback

For the most part motoneurons may be regarded as the slaves of spinal and supraspinal mechanisms which dictate their actions There is a limit beyond which they cannot be driven, however, due to an interesting "governor mechanism Motoneuron discharge frequency normally does not even approach the theoretical limit imposed by the refractoriness following one impulse before recovery of the excitability which permits another impulse The Renshaw feedback imposes a much lower frequency limit than does the refractory period (Eccles [7] may be consulted for a fuller treatment than can be given here, and for references)

Small branches (recurrent collaterals) leave the axons of motoneurons very near the cell bodies and terminate within the cord, rather than emerging in the ventral roots with the axons proper They are thought to excite short interneurons within the cord which fire at unusually high frequencies, usually over 1000 per sec Renshaw first described repetitive discharges in these interneurons in the ventral horn in 1946 and they are now known as Renshaw cells On the basis of physiological evidence, Eccles infers that their short axons pass back into the pool of motoneuron somata where they branch and reach synapses in overlapping and diffuse fashion on motoneurons at the same segmental level Their action on motoneurons is

inhibitory, and since there seems to be no specific inhibition of one functional kind of motoneuron (as flexor or extensor), a coordinating function cannot be attributed to them Presumably they serve to limit motoneuron discharge frequency to reasonable levels and provide a buffer against convulsive activity Much remains hypothetical with respect to this system and it deserves much more investigation

EFFERENT REGULATION OF SPINDLE ACTIVITY
THE GAMMA MOTOR SYSTEM

One of the most intriguing facts to emerge in neurophysiology in recent years is that many receptors, in addition to dispatching signals to the CNS and so playing a vital role in its control of effector systems, have their own activity, or sensitivity, significantly regulated by efferent impulses from the CNS In other words, the CNS does not merely distribute efferent impulses in a pattern dictated by the pattern of afferent impulses it happens to receive In a measure, it can dictate the afferent pattern it will receive This two-way communication between receptors and CNS has been carefully (though not yet fully) analyzed for the muscle spindles Only a brief survey may be presented here but the reader is referred to the excellent monograph by Granit (14) for more detail and references

The motor nerves to skeletal muscles include, in addition to the large *alpha* fibers to the regular muscle fibers responsible for the characteristic contractions, smaller *gamma* fibers which innervate the polar regions of the intrafusal muscle fibers of the spindles Lekskell (26), blocking conduction selectively in alpha fibers by pressure, according to the method described by Gasser and Erlanger in 1929, was able to show that excitation of the gamma efferents evoked a strong afferent discharge from the muscle spindles without producing muscle contraction Presumably, the gamma discharge leads to contraction of the polar regions of the intrafusal fibers This in turn stretches the nuclear bag lying between the polar regions, leading to firing of the stretch receptor, or nuclear bag ending The nuclear bag ending, therefore, can be caused to fire by passive stretch of the whole muscle, which stretches the nuclear bag, or, in the absence of muscle stretch, can be fired by the gamma system Clearly if the gamma efferents are sufficiently acti [illegible]
con [illegible]
trac [illegible]
periment from which Fig 6 4 is taken Spikes are recorded from a single nuclear bag afferent fiber In Fig 6 4A, the spindle discharge is shown to respond to stretch of the muscle producing tensions of 2, 15 and 35 grams, respectively, as recorded by a strain gauge With greater stretch, the frequency of discharge is increased *In Fig 6.4D, the selective stimulation of* alpha motoneurons causes the muscle to contract, as shown by the myogram, and during the contraction the "unloaded' spindles have ceased to fire

Even under initial tension (or load) of 35 gm, the contraction is able to unload the spindle so that it fires only once The effect on the discharge of the same spindle, of stimulating an isolated gamma efferent is shown in Fig 6 4B (nine stimuli at 100/sec in first quarter of each record, as in Fig 6 4D) Even though the spindle is already quite active due to the 35

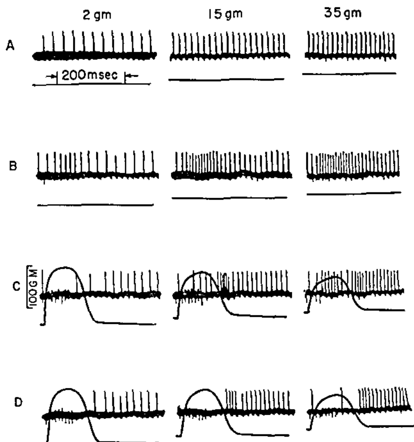


Fig 6 4 Effect of contraction on response to small nerve γ stimulation Recording from single A or spindle receptor from flexor digitorum longus at initial tensions of 2, 15, and 35 gm Second beam indicates strain gauge response A base line discharge B stimulation of isolated γ fiber (9 stimuli at 10 msec intervals at beginning of sweep) Note that effect on afferent discharge increases as muscle

as in B and large α fibers as in D At 2 gm tension there is a pause in the discharge while at 15 and 35 gm, γ stimulation becomes increasingly effective Potentials 0 2 mv Maximal tetanus tension 140 G (Hunt and Kuffler, 24)

gm tension, its frequency increases very perceptibly in response to gamma stimulation In Fig 6 4C, effects of alpha and gamma stimulation (as in Fig 6 4D and Fig 6 4B, *respectively) are combined It is apparent that* gamma discharge can compensate for the loss of tension on the spindle due to muscle contraction As the external force which stretches the muscle is increased (2, 15, 35 gm), the ability of the contraction to "unload' the spindle is decreased, enhancing the effectiveness of the gamma discharge Thus we see the great importance of *initial length* in the normally innervated muscle The more a muscle shortens, the less effective is the gamma discharge in augmenting the contraction through spindle discharge On the other hand, the more the load opposes shortening, the greater the effectiveness of the gamma system in facilitating its motoneurons by exciting spindles

It is helpful to think of the muscle spindles as indicators of *change* in muscle length A reduction of muscle length is indicated by a reduction of spindle discharge and an increase in muscle length by an increased discharge By virtue of the small fiber motor system (gamma efferents) the length of the spindle is kept suitably adjusted to the length of the muscle, so that changes in the latter will promptly affect spindle discharge When the muscle *shortens, the gamma motoneurons excite the spindle fibers and* their contraction "takes up the slack" so that a slight stretch will excite the spindles almost as well as if the same stretch had been applied while the muscle s length was greater

Proprioceptive Reflex Regulation of Gamma Motoneurons

It is reasonable to suspect that the gamma system would be importantly influenced by afferent impulses from proprioceptors in the muscles, tendons, and perhaps the joints, for a controlling system requires a feedback of information from the controlled system in order to control effectively One such feedback to the gamma system has been described by Hunt (23) It is an inhibition of gamma activity by the Golgi tendon organs This makes sense, for if the tendon organs are to be most effective in preventing de*velopment of dangerous tensions, they should* be able to exert their inhibitory influence not only on the alpha motoneurons, but also on the gamma system which, through the spindles, exert an excitatory effect on the alpha neurons Granit (14) states that it is the only known proprioceptive reflex on the gamma motoneurons

The relation between tendon organ discharge and gamma loop activity in Sherrington's lengthening reaction has been beautifully demonstrated as shown in Fig 6 5 (9) The large spikes represent the afferent impulses discharged by one Golgi tendon organ and the small spikes represent afferent discharges from one spindle (*ankle extensors in decerebrate cat) In* Fig 6 5B is the base line discharge of the spindle with the ankle at full extension so the extensor muscle is 'slack In Fig 6 5A, a slight initial

Even under initial tension (or load) of 35 gm, the contraction is able to unload the spindle so that it fires only once The effect on the discharge of the same spindle of stimulating an isolated gamma efferent is shown in Fig 6 4B (nine stimuli at 100/sec in first quarter of each record, as in Fig 6 4D) Even though the spindle is already quite active due to the 35

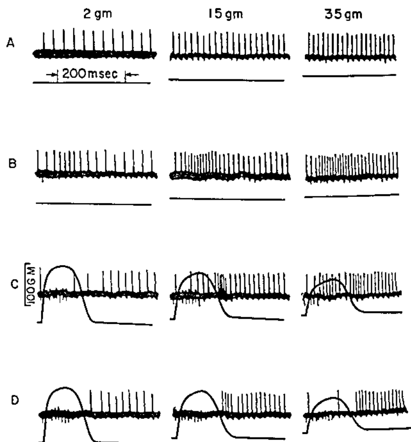


Fig 6 4 *Effect of contraction on response to small nerve γ stimulation Recording from single A or spindle receptor from flexor digitorum longus at initial tensions of 2, 15, and 35 gm Second beam indicates strain gauge response A base line discharge B stimulation of isolated γ fiber (9 stimuli at 10 msec intervals at beginning of sweep) Note that effect on afferent discharge increases as muscle tension is raised No muscle contraction results D similar stimulation of a portion of the ventral root containing no γ fibers Cessation of discharge during contraction C simultaneous stimulation of γ fiber as in B and large α fibers as in D At 2 gm tension there is a pause in the discharge while at 15 and 35 gm, γ stimulation becomes increasingly effective Potentials 0 2 mv Maximal tetanus tension 140 G (Hunt and Kuffler, 24)*

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tension provides a background of spindle activity (small spikes) which is abolished in the first part of the record during a twitch evoked by stimulating ankle extensor motor nerves The large spikes from the tendon organ during this time make it appear probable that the tendon organs inhibit the gamma system The probability becomes a virtual certainty on the basis of records in Fig 6 5C–J which are taken during progressively increasing stretch of the ankle extensors as the experimenter slowly flexes

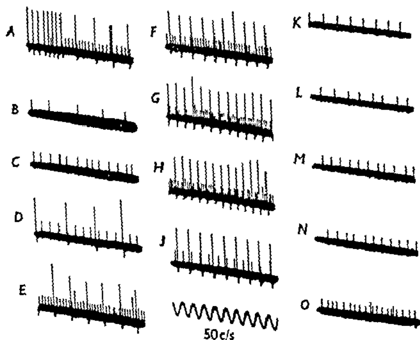


Fig 6 5 *Inhibition of γ discharge by stretch Records from a spindle (small spike) and a Golgi tendon organ (large spike) in the ankle extensors* A *responses during twitch (no myograph)* B *base line discharge with ankle fully extended* C–J *responses during slow continued flexion of the ankle* K *second base line* L–O *response during twist of pinna Decerebrate cat (Eldred Granit, and Merton 9)*

the ankle First, spindle discharge is increased by the stretch Then, as the tension reaches the threshold of the tendon organs the one recorded here begins to fire, slowly at first, then with increasing frequency In Fig 6 5C–H, frequency of *both* spindle and tendon organ increases Suddenly, in Fig 6 5J, there is a marked decline in spindle frequency, just at the time the experimenter feels resistance to passive ankle flexion melt in the typical lengthening reaction The melting is attributed to this sudden reduction of alpha motoneuron facilitation by spindle discharge The relaxation of the muscle relieves the tension on the tendon, which explains the reduced frequency of tendon organ discharge

Cutaneous Reflex Regulation of the Gamma Motoneurons

With carefully graded stimulation, the gamma system has been shown to respond more readily than the alpha system to touch of the skin Granit and his co workers found that twisting the cat s pinna is particularly exciting to the gamma system, often exciting gamma motoneurons alone Sometimes it leads to contraction (alpha system) during which no pause in spindle firing occurs because the gamma activation of intrafusal fibers more than offsets the unloading effect of muscle contraction

The effects of localized stimulation of the skin of a limb, analyzed as shown above by Hagbarth (16), have been shown to be parallel for the alpha and gamma motoneurons Pinching the skin over a limb muscle, either flexor or extensor, excites both its alpha and gamma motor systems, with the latter actually having a lower threshold and generally firing first Thus it appears that the gamma system may serve to prime' the alpha system or serve as a sort of "ignition system ' for it Granit (14) states, In every instance hitherto analyzed the alpha and gamma reflexes have proved to be linked, co excited and co inhibited, often with the gamma reflexes leading All experimenters have been struck by this fact '

SUPRASPINAL CONTROL OF THE ALPHA AND GAMMA SYSTEMS

Considerable literature during the past few years deals with the ascending and descending influence of the brain stem reticular system and its adjuncts It is a massive system of neurons in the brain stem which, through descending reticulospinal pathways exerts facilitatory and inhibitory effects on spinal centers Normally, the algebraic sum of these two opposing influences is positive, i e, it supplies a net facilitation to spinal centers, particularly evident in the centers for the antigravity (chiefly extensor) muscles The spinal animal, with the upper cervical cord transected, for example, presents at first a flaccid, toneless picture of muscular collapse which results from the loss of the net facilitatory support of supraspinal mechanisms, chiefly reticular

The facilitatory and inhibitory portions of the brain stem reticular formation are reasonably distinct anatomically and it is possible to insert electrodes into one or the other part and evoke either facilitation or inhibition of muscular activity The major cause of rigidity in the decerebrate preparation is a tremendous decrease in the activity of the inhibitory portion of the reticular apparatus This leaves the descending facilitatory impulses to exert their effects without the normal countereffects of the inhibitory apparatus The facilitation, unchecked, proves to be dramatically potent, emphasizing the importance of inhibition to the normal distribution of muscle tone

The impressive rigidity of the decerebrate preparation indicates powerful alpha motoneuron activity We have seen that alpha and gamma activity at spinal levels are parallel Do the supraspinal reticular centers, whose influence on alpha activity has become so apparent, exert a like influence on the gamma system? An affirmative answer is provided by experiments (14) with electrical stimulation in which it was particularly easy to obtain selective gamma excitation from many places within the brain stem reticular system Also, by electrical stimulation in the *inhibitory* portion of the reticular formation complete inhibition of both alpha and gamma discharge was obtained Stimulation of anterior cerebellum or the anterior limbic gyrus of the cerebral cortex caused similar inhibition It should be realized that such inhibition is largely due to the fact that the inhibitory reticular apparatus can be activated by excitation of these regions

The demonstration of potent reticular control of the gamma system leads to the question of how important the gamma loop may be in the regulation of muscle activity Granit and his co workers found in a decerebrate cat that experimentally bending the head downward evoked in the soleus muscle both a violent spindle discharge and a violent contraction[5] After de afferentation, eliminating spindle influence on alpha motoneurons, the same procedure resulted in violent spindle discharge, as before (spindles excited by gamma motoneurons) but the muscle failed to contract Granit concludes from this and related experiments that 'the gamma system is there not only to improve the performance of the sense organ but also to serve as an ignition mechanism' to initiate movement as well as to maintain tonus However, in these preparations, rigidity is frequently present *without* spindle hyperactivity and must therefore rely on facilitation without support via the gamma loop Moreover, the cat decerebrated by classical transection may be relied upon to have a high level of gamma, and therefore spindle, activity which is not always accompanied by rigidity

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[5] This is one of the well known tonic reflexes of Magnus It arises in cervical ligaments and serves to align the body with the head Bending the head down inhibits extensors of the fore limbs and excites those of the hind limbs

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7 ERNST GELLHORN

The Physiology of the Supraspinal Mechanisms

SUMMARY

Willed movements are intimately related to reflex movements They depend on sensory mechanisms since the elimination of these mechanisms abolishes voluntary movements in spite of the integrity of the motor pathways Apparently volitional movements involve both sensory and motor systems not only during their execution but also at their very start

Certain areas of the cerebral cortex the classical motor and the supplemental motor area are responsive to electrical stimulation and disclose the representation of movements in the cerebral cortex However it is easily conceivable that complex movements require the activation of several foci at varying intervals and intensities and that the rigid stimulation of one focus is a poor substitute for the processes underlying volitional movements—which are enormously variable

Motor cortical lesions affect bodily movements but recovery of movements following restricted lesions in the motor area gives evidence of extensive overlap in the representation of movement in the motor cortex Restitution of movements following damage of the cortical arm area for instance, seems to be accomplished through arm neurons adjacent to the operatively eliminated area

The movements elicited by electrical stimulation of the motor cortex are modifiable through sensory and particularly proprioceptive influences such as posture and are goal directed in the awake animal For example stimulation of an appropriate cortical site in an anesthetized cat caused aimless activity of the mouth and tongue, while in the waking animal this stimulation elicited not only licking movements but licking applied either to its own body or to the hands of the experimenter

Electromyographic studies of motor units reveal that in the completely relaxed muscle, action potentials are absent, but with very slight voluntary effort action potentials appear With increased effort, rate of discharge of the individual motor unit increases, and a second, and then a third unit are activated, all discharging asynchronously Alternations in the frequency of the discharging units and recruitment of additional units with increasing effort account for the smoothness in the gradation of muscular activity Fatigue causes a reversal of this process the number of discharging units and their frequency of discharge are reduced

The increase in muscular strength under conditions of emotional excitement is due not only to the action of adrenomedullary secretions on the striated muscles but also to the intensification of discharges from the motor cortex resulting from impulses which reach the motor cortex from the hypothalamus

There would appear to be numerous opportunities for making applications of neurophysiological findings in the study of human movement including that associated with therapeutic exercise[1] *It is likely that closer attention to possibilities of these kinds will give rise to worthwhile research activity*

There are several types of observations upon which are based our knowledge concerning the cerebral mechanisms that underlie movements clinical studies dealing with voluntary and involuntary, including convulsive, movements in patients, particularly after the removal of important parts of the cerebral cortex, and animal studies involving the stimulation and ablation of various parts of the brain and the influence of these procedures on spontaneous and evoked movements The stimulation techniques have been greatly refined in recent years and applied to the human brain

THE PHYSIOLOGY OF VOLUNTARY MOVEMENTS

It was mentioned earlier that a spinal preparation (brain and medulla oblongata removed) when maintained under artificial respiration responds to appropriate stimuli with coordinated, predictable reflex movements Similar reflex studies can be performed on animals, in which, in addition to the spinal cord and the medulla oblongata, various parts of the brain stem have been left intact If the brain stem is sectioned rostral to the entrance of the eighth nerve, decerebrate rigidity results The extremities are in a state of extension in such a preparation, but as electromyographic studies show,

[1] See E Gellhorn *Physiological Foundations of Neurology and Psychiatry* Minneapolis University of Minnesota Press 1953 p 116 ff

extensor *and* flexor muscles are continually active On the background of this increased "tone" of the muscles,[2] various types of reflexes including postural reflexes may be elicited on application of appropriate stimuli, but spontaneous movements are absent Similarly it is found that in the "thalamic animal, that is, after the removal of the cerebral hemispheres, spontaneous movements are absent but the distribution of the tone of the muscles is normal A rabbit, for instance, sits in the typical hocking position and responds to suitable stimuli with appropriate reflexes, including some of the complex righting reflexes If animals, particularly dogs, are kept for longer periods of time after bilateral removal of the cerebral hemispheres, 'spontaneous' movements appear They seem, however, to be related to the visceral state of the animal and appear to be accounted for by such factors as hunger contractions of the stomach, a full bladder, and/or distention of the rectum

These observations point to the cerebral cortex as the structure involved in the genesis of volitional movements Although the investigation of the nature of these movements is far beyond the scope of this chapter (and even beyond the task of neurophysiological research), a few facts which are of importance for the occurrence of voluntary movements may be mentioned

Experimental and clinical research shows that voluntary movements of an extremity are abolished in the experimental animal, and greatly reduced in the human, if its sensory innervation is abolished by posterior root section On stimulation of the motor cortex, the threshold is approximately the same on the normal and de afferented sides, indicating that volitional movements may be abolished in spite of the integrity of the efferent system Apparently volitional movements involve both sensory and motor systems not only during their execution but also at their very start Since such 'paralysis' does not result from cutaneous anesthesia, it seems to follow that proprioceptive impulses from muscles and joints play an essential role in the firing of neurons of the motor cortex when voluntary movements are initiated Since such impulses influence, according to some investigators, the motor cortex directly, i e without the intervention of other cortical areas, it is conceivable that simple voluntary movements are initiated in the precentral gyrus However, the experience gained from the study of the aphasias and apraxias suggests that the 'plan" underlying the execution of a group of purposive movements requires the integrity of large sections of the neocortex outside of the precentral gyrus Consequently, it is suggested that any skilled movement 'originates" in cortical areas other than the motor cortex, and that complex patterns of impulses are transmitted to the latter, where, under the influence of proprioceptive impulses, simple and complex patterns of movements in an infinite variety are initiated The completed task is the result not only of the motor cortex and its efferent pyramidal and

[2] This tone is a reflex state since it disappears after elimination of the afferent impulses through sectioning of the posterior roots

extrapyramidal projections, but also of pathways converging from many subcortical and spinal regions

AFFERENT AND EFFERENT PATHWAYS

[illegible]

they account for only 2 percent of the pyramidal efferent fibers The bulk of the pyramidal system originates in other cortical cells They are not confined to the motor cortex proper but comprise the parietal lobe as well The major part of the pyramidal tracts crosses to the opposite side in the decussation of the pyramids, but 10 to 15 percent of the pyramidal fibers remain uncrossed The extrapyramidal system sends efferent fibers from the cerebral cortex (including the motor cortex) to the pons (frontopontine tract), the basal ganglia, the hypothalamus, and the reticular formation in the brain stem

The intimate interrelation that exists between voluntary motor acts and afferent impulses finds its anatomic expression in the fact that the motor cortex is not a purely motor structure but a sensorimotor area, which receives numerous afferent impulses This statement is based on anatomical studies and physiological evidence Although the existence and possible significance of the ascending fibers of the pyramidal system is under dispute (12), physiological experiments indicate that proprioceptive impulses reach the motor cortex even after the elimination of the sensory posterior central gyrus (5) [3]

PHYSIOLOGY OF THE MOTOR CORTEX

Motor Area and Supplementary Motor Area

Since the classical investigations of Fritsch and Hitzig, the motor cortex has been subjected to numerous investigations in various species, with the aid of different types of electrical discharges In recent years the employment of aseptically inserted electrodes made stimulation in the waking animal possible By using threshold stimuli, contractions of muscles were elicited from the precentral gyrus which indicated that the foci for the muscles innervating toe and ankle were found on the medial side, whereas the bulk of the muscles could be brought into a state of contraction from the lateral side of this gyrus On the latter the foci follow this sequence in a rostroventral direction knee, hip, trunk, the arm with the sequence, shoulder, elbow, wrist, hand fingers, then neck and face, and finally tongue and the muscles of the larynx Fig 7 1 shows this arrangement for the human

[3] See also Gay and Gellhorn (6)

FIG 7 1 *The topography of the human motor cortex based on electrical stimulation by Penfield and Rasmussen (From* W *Penfield and* T *Rasmussen* The Cerebral Cortex of Man *New York Macmillan* 1950 *Fig* 22 *Reprinted by permission of The Macmillan Company)*

FIG 7 2 *The limits of the classical motor cortex (precentral gyrus) and of the supplementary motor cortex (medial wall of the brain and sulcus cinguli) in Macaca mulatta (From* C N *Woolsey et al Research Publication Association for Research in Nervous and Mental Disease,* 1952 30 244 *Reprinted by permission)*

cortex and indicates in the 'motor homunculus that the distal parts of the limbs (and particularly of the arm) are represented more widely in the motor cortex than the proximal parts, and that movements of the lips are elicited from a much larger area than those of the forehead Since that the large muscles of the trunk are activated from a very small area, it follows that the responsiveness of striated muscles to stimulation of the motor cortex is unrelated to the mass of the muscles This finding is likewise indicated in work of Woolsey (18) on monkeys, which show at the same time that the trunk muscles are not separated from the face by the arm area but that the motor pattern in the cortex hangs together much as does the actual musculature'

Recent studies by Penfield (24) on the human cortex disclosed a *supplementary motor area* located within the longitudinal fissure just anterior to the representation of the foot in the motor cortex Stimulation of this area produces complex combinations of movements in which the contralateral hand is typically raised before the face and the head and eyes turned to the hand Figs 72 and 73 show this area and the distribution of foci for the monkey The efferent fibers of the supplementary motor area belong to the pyramidal system They send impulses to the contralateral and ipsilateral muscles of the body, but the numerical superiority of the crossed fibers is less pronounced than in the pyramidal system originating in the classical motor area (1)

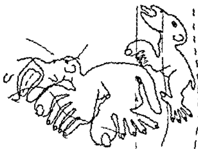


FIG 73 *The localization pattern of motor and supplementary motor cortex in Macaca (From C N Woolsey et al Research Publication Association for Research in Nervous and Mental Disease 1952 30 245 Reprinted by permission)*

CENTRAL OVERLAP AND MULTIPLE REPRESENTATION OF MOVEMENTS IN THE CEREBRAL CORTEX

The investigations described above disclosed the general anatomical arrangement of the cortical foci from which with threshold currents and often with single shocks a contraction of the various muscles of the body may be obtained, but they fail to give an insight into the contribution of the motor cortex to the performance of integrated movements However, if the motor cortex is stimulated with repetitive stimuli for a few seconds, movements result which reveal the full potentials of the motor cortex Under these conditions not single muscles but groups of muscles are contracted in a definite order Simple coordinated movements are thereby produced There is a considerable overlap of the areas from which move

ments activating the various joints of the leg or of the arm are elicited, and a similar statement applies to the face and head area Even in the monkey the cortical areas for movement of the hip, knee, ankle, and toes practically coincide, as do the boundaries for movements of the shoulder, elbow, wrist, and fingers

Surgical isolation of small blocks of cortical tissue gives further evidence that movements are represented severally rather than singly in the motor cortex (13) Stimulation of cortical foci located in such isolated blocks of cortical tissue elicits multiple movements similar to those obtained on the stimulation of the normal cortex This suggests that neither a physical spread of the current nor the physiological activation of neurons located in adjacent parts of the cortex accounts for the simultaneous or successive activation of several muscles following stimulation of a cortical focus By means of electromyographic records, it could be shown that the cortical threshold of several functionally interrelated muscles is practically the same (7) Consequently, even with threshold stimuli, a movement involving several muscles results rather than the isolated contraction of a single mus cle

From these and similar observations it is concluded that the motor cor tex does not consist of a mosaic of anatomical foci of individual muscles, but is so organized that the production of movements involving many muscles results from the activation of each cortical 'focus' Similarly, it was found that contractions of single muscles do not occur even in weak, re stricted voluntary movements apposition of index and thumb involves a contraction of the muscles of the hand and forearm, and the movement of one finger is associated with a change in the tone of other digital muscles (16)

The central overlap in the motor cortex of the foci of many muscles seems therefore to be responsible for the more or less complex movements resulting from stimulation of the motor cortex This phenomenon accounts also for the fact that volitional movements consist of patterns of con tractions of muscles, but not of the contraction of a single muscle The study of the spread of convulsive activity over the motor cortex in Jack sonian epilepsy reveals, likewise the extensive overlap in the human cortex (15) Finally, this overlap has been verified anatomically lesions in the hand or thumb area of the motor cortex in monkeys cause degeneration not only in the cervical thoracic segments of the spinal cord but also at the lumbar level (9)

Movements elicited by stimulation of a site in the precentral gyrus are characterized by their coordinated character If, for instance, a flexion of the right forearm is induced by stimulation of a site of the left cortical arm area, the spatial distribution and temporal sequence of the activated muscles is similar to that seen when such a movement results from volition As the stimulating electrode is moved from the lateral to the medial part of the

precentral gyrus, the following fundamental types of movements of the limbs are noted in the lightly anesthetized macaque

1 flexion of the elbow with extension of the wrist and protraction of the arm
2 extension of the elbow, flexion of the wrist and retraction of the shoulder
3 flexion of the knee and dorsiflexion of the ankle
4 [illegible]

[illegible] ked movements [illegible] ted by the following observations whereas cortical [illegible] predominantly contralateral movements of the extremities the movements of the jaw and vocal cords involve both sides, as in chewing and speaking Furthermore, the effect of cortical stimulation is not confined to the somatic nervous system but involves the autonomic system as well The flexion of the left arm as the result of cortical stimulation is associated with an increased circulation of the blood through the contracting muscles On the contrary cortical areas such as the gyrus cinguli, which on stimulation reduce the activity of the skeletal muscles, at the same time reduce blood pressure heart rate, and often also respiration

Comparison of Volitional and Cortically Induced Movements

Compared with the enormous variability of voluntary movements the paucity of the experimentally evoked types of movements has frequently been stressed It should not be forgotten however, that in general only a small fraction of the motor cortex was stimulated in physiological experiments The importance of the cortex hidden in the depth of the sulci has been shown recently (3) Moreover, it is easily conceivable that complex movements require the activation of several foci at varying intervals and intensities, and that the rigid stimulation of one focus is a poor substitute for the processes underlying volitional movements

In addition, it should be borne in mind that changes in the frequency of stimulation cause alterations not only in the intensity but also in the quality of movements (shift from a flexor to an extensor movement and vice versa) In this respect it is of interest to mention that several muscles activated from a certain cortical focus show their optimal response at different frequencies, moreover, the same muscle activated from different cortical foci shows different frequency optima (11) The latter observation has been confirmed at the microscopic level by the study of unit potentials in the muscle,[4] since the same unit may show different frequency optima when activated from different cortical sites (10) These observations suggest that

[4] The action potentials are recorded by means of microelectrodes from a few muscle fibers These potentials are due to the discharge of single neurons in the motor horn cells of the spinal cord (unit potentials)

the systematic variation of the frequency and site of stimulation may lead to a great variability of cortically induced movements It may be further assumed that *the excitatory process accompanying volitional movements* induce different rates of cortical discharge in various parts of the motor cortex and thereby account for the multiplicity of these movements

Finally, anesthesia limits the responsiveness of the motor cortex Recent experiments with implanted electrodes disclosed in the unanesthetized animal the following important facts concerning cortically induced movements

1 *They were* "*so natural and appeared so normal, that it was necessary* to repeat the observations several times to be sure that they were evoked and not spontaneous' (2)

2 When a movement was evoked while the animal was walking, a summation between the evoked and the spontaneous movement resulted

3 The cortically induced movements, just as the volitional movements, are goal directed As Delgado expressed it, responses to cortical stimulation "are not blind contractions of some muscles nor the blind performance of a movement, but the orderly use of groups of muscles, with the capacity of functional adaptation if the experimental conditions should change'

This finding may be illustrated by two examples A site of the cortex was stimulated which leads to the turning of the head in the horizontal plane Then this movement was opposed by an obstacle (hand of the experimenter or book) On repetition of the stimulus the animal raised its head and then turned it, thus avoiding the obstacle and carrying out the movement, 'movements varied, the action remained constant" (2) The second observation concerns the cortically induced licking Stimulation of an appropriate site in the anesthetized cat caused "aimless phasic activity" of mouth and tongue, but in the waking animal this stimulus elicited not only licking movements but licking applied either to its own body or to the hands of the experimenter The close resemblance in these observations between cortically evoked and voluntary movements is evident

The Effect of Lesions of the Motor Cortex

The importance of the motor cortex for volitional movements is apparent from the effect of lesions of this area The paralysis following such lesions depends in its degree and duration on their size, the species, and the age of the animal It increases in severity with increasing phylogenetic development and is more marked in mature than in young animals Bilateral removal of the motor cortex (including the area six located in front of the *precentral gyrus*) *in anthropoids virtually abolishes all voluntary movements* Lesions restricted to the area four do not lead to permanent paralysis except in the distal parts of the limbs The recovery following more restricted lesions in the motor area gives further evidence for the extensive

overlap in the representation of movements in the motor cortex The paralysis of the contralateral arm is greater after the cortical arm and leg area are removed than after the elimination of the arm area alone Moreover, even small lesions lead to a weakness in many movements involving several joints!

When, following the removal of the left cortical arm area, the movements of the right arm have been restored after an adequate period of time, the cooling of the left motor area abolishes these movements temporarily The restitution of the movements seems to have been accomplished through intact "arm" neurons adjacent to the operatively eliminated area

It was emphasized earlier that volitional movements require sensorimotor integration Elimination of a part or of the whole of the motor area produces some sensory, particularly tactile, disturbances which may account for spasticity (4) These disturbances may result in a rise of the threshold of the remaining intact efferent neurons

Reduction in the number and changes in the excitability of the efferent neurons seem to be the chief factors accounting for the various degrees of paralysis which follow lesions in the motor area To what extent the supplementary motor area, the so-called second motor area—located between the lower end of the Rolandic fissure and the fissure of Sylvius (14)—and the uncrossed efferent neurons originating in the homologous area of the cortex on the opposite side, contribute to the restitution of movements is not well known

ELECTROMYOGRAPHIC STUDIES

The insertion of electrodes in many muscles through the recording of the electromyogram (EMG) permits better insight into the quantitative aspects of movements than does mere inspection These methods have greatly contributed to the understanding of the mechanisms underlying voluntary movements and the action of the motor cortex, particularly under the influence of afferent impulses

In addition, the activity of single motor units was studied in man during voluntary movements, and in animals during stimulation of the motor cortex This work gives valuable information on the physiological principles underlying the gradation of movements

Voluntary Movements

When the muscles of the arm are completely relaxed, action potentials are absent, but with very slight voluntary effort action potentials appear Records obtained through microelectrodes disclose that with increasing effort more units are called into action, moreover, the frequency of the rate of discharge of the individual unit increases This frequency may vary between 5 and 50 per sec Fig 7.4 shows the behavior of three different units during flexion

of the ankle with increasing degree At the weakest effort only one unit discharges As the effort increases, the rate of discharge of this unit increases, then another unit goes into action while the first unit approaches its maximal rate of discharge Similar changes are seen as the third unit is activated The discharges in various units are asynchronous Alterations in the frequency of the discharging units and recruitment of additional units with

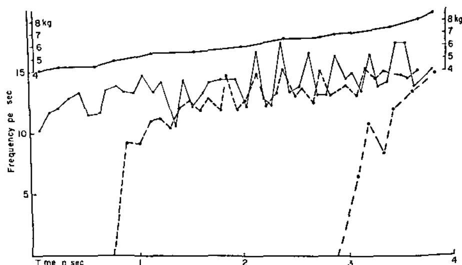


Fig 7 4 *The behavior of three motor units in the m tibialis anticus of man during voluntary ankle flexion More units come into action with increasing tension and attain a frequency 12 to 15 discharges per sec (From H Seyffarth see* E Gellhorn Physiological Foundations of Neurology and Psychiatry *Minneapolis University of Minnesota Press, 1953 Fig 4)*

increasing effort account for the smoothness in the gradation of muscular activity Fatigue causes a reversal of these processes the number of discharging units and their frequency of discharge are reduced

Motor Cortex

Stimulation of a site of the motor cortex with currents of increasing voltage or frequency lead to increased movements or, under conditions of isometric recordings, to increased tension This is reflected in the EMG of the whole muscle by the increased amplitude of the potentials Microrecords show that increasing excitation of the motor cortex changes the activity of individual motor units in the same manner as under the influence of voluntary effort the individual neuron increases its rate of discharge, additional neurons are "recruited" and finally, the duration of the discharge increases Excitation of the motor cortex through such stimuli is reflected also in the activity of the pyramidal tracts of which the rate of discharge has been recorded with microelectrodes Single impulses or groups of two or three occur in anesthesia

They are not accompanied by visible movements. A single shock, although increasing the discharge rate, does not elicit movements. With repetitive stimuli the frequency of the rate of discharge of an individual neuron increases, and new neurons are activated. At the same time, movements appear.

The gradation of movements (reflex, voluntary and those resulting from the stimulation of the motor cortex) involves the same principle: increase in the frequency of the rate of discharge and recruitment of an increasing number of neurons with increasing degrees of stimulation (Adrian-Bronk Law).

Proprioceptive Influences

Electromyographic studies have disclosed a twofold effect of proprioceptive influences on movements elicited by the stimulation of the motor cortex: (1) the movements are strongly enforced by proprioceptive impulses and (2) proprioceptive impulses determine within certain limits the type of movement that is evoked by stimulation of a certain cortical focus.

Electromyographic records show that the functional units called into action by stimuli applied to the motor cortex in a medial-lateral progression are: (1) hamstrings-triceps-flexor carpi muscles, (2) the triceps-flexor carpi combination (triceps complex) and (3) the biceps-extensor carpi group (biceps-complex).

These cortically induced patterns of innervation are greatly altered by proprioceptively induced reflexes. Such reflexes may be evoked by changing the length of a muscle or group of muscles through an alteration of the position of a limb (e.g. the elbow was placed at an acute or obtuse angle). Gross observations and EMG records showed that the responsiveness of muscles to a cortical stimulus increased with increased stretch.

Thus the triceps response to a given cortical stimulus is greater when the angle of the elbow is at 45° than when it is at 110° or 160°, whereas the response of the biceps changes in the reverse direction. Similar findings were made on gastrocnemius, tibialis anticus, and on the carpal muscles when the position of ankle and wrist respectively was changed. The increased response was indicated by the increased amplitude of the EMG and the shortening of the summation time.* In addition a cortical stimulus which was below the threshold when the muscle was slack (biceps at an acute angle of the elbow) became effective when the muscle was stretched through an appropriate alteration of the position of a joint. The effect of proprioceptive reinforcement is even greater when the muscle contractions are recorded under isometric conditions. Thus fixation of the knee at an acute angle favors greatly the response in the quadriceps, while the activity of the hamstrings is augmented at a fixation of this joint at an obtuse angle (Fig. 75).

* I.e. the interval between the beginning of the stimulus and the onset of the EMG.

It is notable that under proper conditions the proprioceptive impulses decide which type of innervation pattern appears if the cortex in the bi phasic (biceps triceps) area is stimulated With the elbow in flexion, action potentials appear in the triceps during stimulation and in the biceps only as a weak after discharge with the elbow in extension, no activity is seen in the triceps, whereas potentials in the biceps occur during the stimulatory period and also as an after discharge These results are similar to observations on unanesthetized animals in which stimulation of a certain focus in the motor cortex evoked a flexion of the arm when the arm was extended, but an ex tension when it was flexed before the application of the stimulus (17) Apparently impulses are sent to agonist and antagonist at the same time un



Fig 7 5 The influence of fixation of the knee at 45° (a b and a , b) and at 165° (a' b) on the response of the quadriceps (upper line) and ham string (lower line) muscles to stimulation of the motor cortex in the monkey The electromyograms show that the response of the stretched muscles is greatly increased (From E Gellhorn Physiological Foundations of Neurology and Psychiatry *Minne apolis University of Minnesota Press 1953 Fig 23)*

der these conditions, and the increase in the excitability of the neurons of the muscle in the state of stretch and/or isometric contraction, based on proprioceptive reflexes, determines the type of movement in the unrestricted limb or the pattern of innervation in the fixated extremity

The interrelation of the muscles resulting from the action of proprioceptive impulses is more complex than has been indicated thus far Fixation of a single joint changes the degree of contraction in many muscles Those mus cles which show an increased EMG response to cortical stimulation on fixa tion of the elbow in flexion comprise the triceps complex, whereas the mus cles showing an increased response to cortical stimulation on fixation of the elbow in extension are said to belong to the biceps complex

Table 7 1 `
the elbow th
while the tri
bow, the flexors of the wrist and fingers and most of the shoulder muscles *with the exception of the acromiodeltoid muscle* It is suggested that fixa tion of one or more joints at certain angles under isometric conditions

may, through proprioceptive reinforcement, greatly increase activity in previously paretic muscles

The similarity existing between willed movements and those elicited by stimulation of the motor cortex was pointed out repeatedly There are, however, significant differences The motor patterns observed on stimulation of the motor cortex are fixed within certain limits whereas volitional movements may produce a limitless variety of new patterns This difference may

TABLE 7 1 Muscles Constituting Biceps and Triceps Complexes

Biceps complex	*Triceps complex*
Biceps	Triceps
Extensor carpi radialis	Flexor carpi ulnaris
Extensor carpi ulnaris	Flexor carpi radialis
Extensor digitorum communis	Palmaris longus
Pronator teres	Flexor digitorum sublimis
Abductor pollicis longus	Flexor digitorum profundus
Abductor pollicis	Dorsoepitrochlearis
Supinator	Pectoralis major
Extensor digitorum proprius II and III	Trapezius
Extensor digitorum proprius *III* and *IV*	Latissimus dorsi
Brachioradialis	Infraspinatus
Brachialis	Supraspinatus
Acromiodeltoid	Spinodeltoid
	Teres major

be illustrated by a single experiment It was emphasized that the contraction of the biceps muscle is associated with that of the extensor carpi, whereas the contraction of the triceps is associated with that of the flexor carpi on stimulation of the motor cortex

In voluntary movements the association of muscles in groups is more variable and solely determined by the intended movement Thus voluntary flexion of the wrist against a resistance is aided by the biceps in supination but by the triceps in pronation The effect of various movements of the wrist on the innervation of the biceps and triceps in shown below

Movement	*Agonist*	*Associated Muscle*
Flexion in pronation	Flexor carpi	Triceps
Flexion in supination	Flexor carpi	Biceps
Extension in pronation	Extensor carpi	Biceps
Extension in supination	Extensor carpi	Triceps

EMOTIONS AND THE MOTOR CORTEX

It is well known that emotional excitement greatly increases muscular performance and delays fatigue This latter phenomenon is usually explained by

the liberation of neurohumors from the adrenal medulla and their action on the striated muscle (Cannon) Since the emotions cause an excitation of the hypothalamus, the influence of hypothalamic stimulation on the movements elicited by stimulation of the motor cortex is of interest Such studies showed that hypothalamic stimulation, which by itself does not elicit a movement, increases the intensity of a cortically induced movement Moreover, the movement becomes more complex, involves, under the combined influence of cortical and hypothalamic stimulation, many muscles which were not activated by the cortical stimulation alone and may even spread to other extremities This striking effect is due to summation processes which take place at two sites (1) in the spinal cord as the result of the interaction of the subthreshold extrapyramidal discharges from the hypothalamus and of the efferent discharges from the motor cortex, and (2) in the motor cortex itself due to the intensification of pyramidal discharges as the result of hypothalamic cortical discharges (8) Since these hypothalamic cortical discharges consist of unspecific sensory impulses which influence the cerebral cortex in general, it may be said that the increased muscle power in emotion is just another example illustrating the profound influence of sensory impulses on cortically induced movements

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8 HENRY LONGSTREET TAYLOR

Exercise and Metabolism

SUMMARY

Physical activity requires energy for its performance and this energy is derived from oxidation of food stuffs Food is stored in the body in the form of fat and carbohydrate But since there is no reserve of oxygen, only a small quantity of it is in transit to the tissues in the lungs and blood stream Therefore if one wishes to study energy expenditure (i e, energy metabolism) the measurement of the oxygen consumption is a convenient way of doing so It has been found that the minute by minute energy expenditure is accurately reflected in the oxygen intake until high levels of work are reached when the muscle calls on metabolic mechanisms which release energy temporarily without a concurrent utilization of oxygen This results in an excess oxygen consumption during recovery which is called an oxygen debt The energy requirement of high level work loads is properly calculated as the sum of the oxygen consumption during work plus that after work Since it is clear that certain organs (such as the brain) require oxygen during rest and continue to do so during work, it is assumed (without much real proof) that the basal metabolic oxygen consumption continues during work So the total oxygen used during work and recovery has subtracted from it, the oxygen that would have been used if the metabolic rate continued without change The result, expressed either as a total amount (liters of oxygen) for a given task, i e, running 440 yards or as a rate (liters of oxygen per minute), is the oxygen requirement of the task in question

Work tasks may be classified by the energy requirement and this is best done as multiplier of the basal oxygen consumption Most industrial tasks require oxygen at a rate of three times the basal oxygen intake Work tasks requiring eight times the basal O_2 consumption are considered heavy work but can be maintained for long periods by young men who are only in average physical condition These tasks are generally referred to as aerobic or sub

maximal work In the aerobic work situation the heart and lungs can supply oxygen at a rate that keeps up with the requirements Work tasks that require 10 to 15 or more times the basal oxygen consumption are characterized by an inability of the cardiovascular pulmonary system to supply O_2 at the required rate and the difference must be made up by the oxygen debt Such tasks can be maintained for relatively short periods of time usually less than five to seven minutes and are referred to as anaerobic or maximal work

Factors affecting the oxygen consumption have been worked out in the greatest detail for tasks of progression i e walking running stair-climbing bicycle riding, swimming etc A great deal of research has been done on industrial tasks and those of everyday life But the student of modern athletics will find that with the exception of track most sports requiring a high level of energy expenditure such as football tennis basketball wrestling and boxing have not been studied in detail because no one has developed apparatus which will allow a player to take part in such sports and still collect the expired air necessary for such measurements

In walking speed and body weight are important variables affecting the oxygen intake while such things as age race sex and environmental temperature have no effect whatever Training has little effect on the oxygen consumption of walking because everyone walks and has developed a high degree of skill On the other hand in running it is easy to show that repetition by people who have done little or no running in the past reduces the oxygen requirement This means that they can run at a given pace with less energy expenditure or can run a given distance at a higher speed All this provides a physiological explanation for the observation that practice by the performer and attention to form by the coach will improve performance

Skill can be studied by determining what is called the mechanical efficiency of work The mechanical efficiency of work is simply the percentage of energy a man expends in performing a specific task that can be converted to useful work This can be expressed in the following way

$$\text{efficiency (in percent)} = \frac{\text{calorie equivalent of external work}}{\text{calories used in doing the work}}\ 100$$

When this is done it is found that work can be done most efficiently at a speed of muscular contraction which is substantially less than maximal Tasks demanding a high speed of muscular contraction are wasteful of energy This fact can be demonstrated on both the intact individual and in the isolated muscle

An interesting observation is that if a muscle is contracted and then forcibly stretched energy is absorbed by the muscle and work of this kind can be carried on for long periods with low energy expenditures and little accumulated fatigue

In maximal work the oxygen consumption becomes stable and no longer increases with an increasing work rate It is clear that this happens because

the cardiovascular respiratory system can no longer increase the delivery of oxygen to the working muscles Additional energy necessary to carry the cost of work loads above that at which the O_2 intake becomes maximal is derived from the ability to metabolize carbohydrate to release energy to the muscle and then build up an oxygen debt This makes it possible to prove that the maximal oxygen consumption has been attained and lays the groundwork for an objective test of cardiovascular pulmonary fitness which is not dependent on either skill or motivation It is easy to show that performers such as long-distance runners who are to perform tasks of high energy expenditure over a prolonged period must have large maximal oxygen intakes Contrariwise, the sprinter will benefit from the capacity to accumulate a large oxygen debt Oxygen debts are difficult to study because much equipment and time is required The validity of estimating the oxygen debt from determinations of the concentration of lactate (an end product of the metabolic process which supplies the muscle with energy in the absence of oxygen) is discussed

There is currently some debate about the value of the warm up before athletic contests It is easy to demonstrate that 10 minutes of grade walking before the maximal oxygen test will increase the capacity to move oxygen to the muscles by 5 percent thus increasing the endurance of the athlete

A problem of considerable theoretical interest is what factors force the cardiovascular pulmonary system to stop increasing the amount of oxygen delivered to the muscles This is discussed but not completely resolved

It can be shown that obtaining energy from the oxygen debt mechanism is an inefficient process which increases the cost of the work Studies of the oxygen cost of running to exhaustion at a steady pace over specified distance or starting fast and ending at a slower rate indicate that both are wasteful of the runner's energy and that a given distance will be covered in a shorter time if the runner starts slowly and ends the race with a sprint The latter plan has been considered good tactics for races of a mile or longer by the coaching professions but there has been disagreement regarding the 880 and 440 It is clear that there are a large number of practical problems in the management of athletes that could be solved by careful study of energy requirements

In the last analysis all cellular activity and particularly muscular activity is supported by energy derived from the oxidation of food stuffs However the energy used by the contracting muscle appears to be drawn from high energy phosphate bonds built up by a complex chain of chemical reaction which originated with actual oxidation Energy can be stored in the muscle both in the high energy phosphate bonds and in the form of glycogen Both these sources can be called in to supply energy for muscular contraction in the absence of any active oxidation In this situation the muscle acquires in

the words of A V Hill, "an oxygen debt' which is paid off by excess oxygen consumption at some later time The quantity of energy which may be used for physical work without oxidation to rebuild the energy stores of the muscle is strictly limited so that the great majority of physical work done by man is carried on at rates which allow the oxidative mechanisms to keep pace with the energy requirement

Since all physical activity is eventually paid for by the utilization of oxygen in the oxidation of food stuffs, the relationship between oxygen consumption and physical activity is of first importance in the understanding of physical activity It is the purpose of this chapter to examine the relationship between oxygen intake in man and the rate and type of work on the one hand and factors which influence *the type of muscle metabolism (i e, aerobic versus* anaerobic metabolism) on the other

METHODS

The time honored procedure of using a Douglas Bag or a balanced spirometer to collect expired air, combined with analysis of the collected air by some modification of the method developed by Haldane, is still the most frequently employed procedure for studying oxygen consumption Closed circuit systems have been and still are employed in special situations, the most recent application being the study of the dynamics of oxygen debt Application of modern physical principles to the problem of gas analysis has resulted in commercially available devices which can provide analytic values for the concentration of oxygen and carbon dioxide (58) A separate system is required for the analysis of each component Use of equipment of this kind, although expensive, has enormously increased the number of observations that can be made in one day

In addition to this advantage the investigation of the metabolic cost of work has recently been presented with two devices which measure accurately the respiratory volume and take a 0 3 to 0 6 percent sample of the expired air and segregate it for analysis in a small sample bag (55) Equipment of this kind has made it possible to leave the confined area of the physiological laboratory and to make observations in daily tasks in the home, the factory, and the playing field which were not possible before The use of these instruments has greatly increased the number of situations in which the energy cost has been investigated (67) All the variations of this kind of apparatus cannot be used in situations that demand very high rates of pulmonary ventilation At rates of 40–50 liters/minute the instruments begin to show faulty ventilation values This limits their application to sports requiring high energy expenditure

On the other hand these instruments have made it possible to accumulate a great deal of information on the energy costs of tasks carried out in

weight in Northern Europe and North America will not be very far removed from the time honored figure of 70 kilograms which physiologists have an unfortunate habit of referring to as an average man Uncorrected figures such as those used by Christensen and accepted by Passmore and Durnin (67) can be grossly misleading in individual cases and in making comparisons between such diverse ethnic groups as Swedes and Japanese

Other methods of classifying work tasks can be used Many physiologists as a practical matter regard a task which exhausts a man in three to seven minutes as belonging automatically in the maximal work category It has been customary in the Laboratory of Physiological Hygiene to refer to those tasks which produce exhaustion in well motivated individuals in four to eight minutes as maximal or anaerobic work

FACTORS AFFECTING THE OXYGEN INTAKE PART ONE SUBMAXIMAL OR AEROBIC WORK

1 *The Course of Oxygen Consumption During Work*

When a man undertakes a steady rate of work which can be maintained for a long period, his oxygen consumption follows a well known course It is characterized by a period of increasing oxygen consumption which continues for approximately three to five minutes and is followed by a constant rate of oxygen consumption This latter phase is referred to as a steady state with regard to oxygen consumption After work has stopped, the rate of oxygen uptake falls rapidly a ithmic function of time Oxygen intake continues at a rate which i of that found under basal condition before work for a period o is related to the intensity of wor The total of the oxygen co excess of basal requirements af work is referred to as the e size of the oxygen debt submaximal work is directly lag in the oxygen intake a beginnin of work in reachi when the oxygen intake the re

real life situations It is clear that apparatus which can assess accurately the high energy expenditures of many sports would be extremely useful

CLASSIFICATION OF WORK TASKS

A work task can be classified by its energy requirements For the great majority of work tasks which can be maintained for periods of 20 minutes or more, the oxygen intake per minute is less than the oxygen requirement However, as the oxygen requirement increases, a point is reached at which the cardiovascular respiratory system no longer can increase the amount of oxygen delivered to the muscles In maximal work tasks of this kind the requirement is always greater than the intake, the balance being made up by the energy supplied by the anaerobic glycolysis of glycogen to lactic acid which can be measured as oxygen debt

Several classifications of work tasks by energy levels have been made Dill (26) proposed that moderate work be defined as tasks that required oxygen at a rate that was up to three times that observed under basal condition Hard work was classified as ratios (work metabolic rate/basal metabolic rate) of from three to eight These two classifications encompass the great majority of industrial jobs Dill recognized an intermediate zone that existed above his classification of hard work and then classed as maximal work those tasks eliciting a maximal performance of the cardiovascular respiratory system In the untrained man this may mean a W M R /B M R of 10 and in the trained individual a ratio of 20 It is in the area in which energy requirements are above a metabolic ratio of eight that a large fraction of sports activities lie while with very few exceptions, industrial occupations are placed below a ratio of eight Indeed, in modern America most industrial jobs have metabolic ratios of three or less

Christensen (20) has classified industrial tasks by the energy required per minute in the following way

a unduly heavy	energy expenditure over	12 5 cal /min 2 5 l O_2/min
b very heavy	energy expenditure over	10 cal /min 2 l O_2/min
c heavy	energy expenditure over	7 5 cal /min 1 5 l O_2/min
d moderate	energy expenditure over	5 cal /min 1 0 l O_2/min
e light	energy expenditure over	2 5 cal /min 0 5 l O_2/min

There is no objection to such a fine breakdown but Dill s method has the great advantage of examining energy requirements of work independently of body size It is true that if one studies groups of workers, the mean

weight in Northern Europe and North America will not be very far removed from the time honored figure of 70 kilograms which physiologists have an unfortunate habit of referring to as an average man Uncorrected figures such as those used by Christensen and accepted by Passmore and Durnin (67) can be grossly misleading in individual cases and in making comparisons between such diverse ethnic groups as Swedes and Japanese

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the requirement

2 Body Weight and Speed in Tasks of Locomotion

Factors which affect the oxygen intake during aerobic work will, of course, vary with the kind of task which is to be undertaken In any task which involves transporting the body from one place to another, body weight will be an important factor, the speed at which this is done will occupy an important place in a list of factors, and finally, the skill with which the task is performed will be consequential particularly in those tasks which require

possible since it developed that the relationship is curvilinear rather than linear

As in the case of walking on the level, the body weight turns out to be the most important variable in walking on a specific grade Erickson, *et al* (31) studied 47 young men walking on a 10 percent grade at 3 5 miles per hour Observations on all these men were made on several occasions The results were presented in Table 8 1

The figures in columns 1 and 2 of Table 8 1 represent the several sources of variability which are readily obtained from a test retest set of data These figures are the standard deviations which were calculated as the square root of the variance (16) The variability attributed to individuals is the largest item when the gross oxygen consumption is examined When the oxygen

TABLE 8 1 Inter and Intra Individual Variability of the Oxygen Consumption of 47 Subjects During Walking on the Treadmill at 3 5 Miles per Hour on a 10 Percent Grade (O_2 Cons)

	Gross	Cc Kg of Body Wt
Mean ml /min	1839 2	25 97
Percent of the mean		
Individual S D	9 37	3 99
Trial S D	2 68	2 50
Error S D	2 17	2 11

consumption is expressed as cc per kilogram of body weight, the variability attributed to individuals is reduced to a figure which is only a little larger than that accounted for by the variability between trials and the residual variability not accounted for by the other two items This means that one can predict the oxygen consumption at a given speed and grade from body weight with almost as much accuracy as one can measure it The work of Erickson, *et al*, Mahadeva, *et al* and consideration of the data presented in Fig. 8 1 lead to the conclusion that the skill (mechanical efficiency) of walking on either the level or on a grade on the motor driven treadmill is remarkably constant from one individual to another

The observation regarding the skill component of walking illustrated in the preceding section is the exception rather than the rule The usual experience is to find rather large differences in indices of skill which can be formulated in terms of oxygen consumption A good example is the work of Dill, Talbott, and Edwards (28) who reported a number of observations on 12 men who ran on the motor driven treadmill at 9 3 kilometers per hour on a zero grade for 20 minutes The oxygen consumption varied from 1 8 to 2 7 liters of oxygen a minute The mean oxygen consumption per kilo-

and race had no appreciable relationship to the metabolic cost of work The relationship between energy expenditure and body weight could be described by the equation

$$C = 0.047W + 1.02$$

where W = weight in kilos and C = kilo calories.

A systemic study of speed and weight in walking on the level has not been carried out However, Passmore and Durnin (67) have combined these

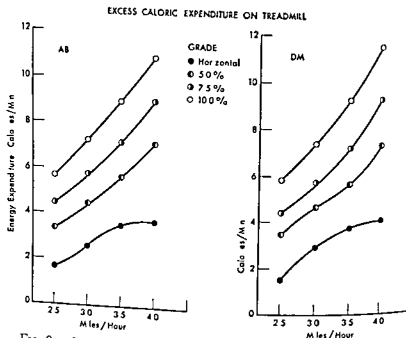


FIG 8 2 *The effects of treadmill speed and grade on the excess caloric expenditure due to work in two young men walking on the motor driven treadmill Data of Erickson* et al (31)

two equations to predict energy requirements at specific speeds and weights

Grade walking has been investigated in numerous laboratories This is particularly true of walking on a grade on a motor driven treadmill because investigators have found this to be a useful method of imposing graded work loads on subjects who were being used in investigations of the relationship of work to variables such as nutrition and environmental temperature

The relationship between speed and grade is presented in Fig 8 2 taken from the work of Erickson, *et al* (31). An attempt was made to fit these data to an equation of the general form, $O_2 = AS + BG + C$, where O_2 = oxygen consumption in liters per minute, S = speed in miles per hour, G = grade in percent, and A, B, and C were constants But this was not

possible since it developed that the relationship is curvilinear rather than linear.

As in the case of walking on the level, the body weight turns out to be the most important variable in walking on a specific grade Erickson, *et al* (31) studied 47 young men walking on a 10 percent grade at 3 5 miles per hour Observations on all these men were made on several occasions The results were presented in Table 8 1

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Trial S D	2 68	2 50
Error S D	2 17	2 11

consumption is expressed as cc per kilogram of body weight, the variability attributed to individuals is reduced to a figure which is only a little larger than that accounted for by the variability between trials and the residual variability not accounted for by the other two items This means that one can predict the oxygen consumption at a given speed and grade from body weight with almost as much accuracy as one can measure it. The work of Erickson, *et al*, Mahadeva, *et al.*, and consideration of the data presented in Fig 8 1 lead to the conclusion that the skill (mechanical efficiency) of walking on either the level or on a grade on the motor driven treadmill is remarkably constant from one individual to another

The observation regarding the skill component of walking illustrated in the preceding section is the exception rather than the rule The usual experience is to find rather large differences in indices of skill which can be formulated in terms of oxygen consumption A good example is the work of Dill, Talbott, and Edwards (28) who reported a number of observations on 12 men who ran on the motor driven treadmill at 9 3 kilometers per hour on a zero grade for 20 minutes The oxygen consumption varied from 1 8 to 2 7 liters of oxygen a minute The mean oxygen consumption per kilo-

gram of body weight was 32 16cc per minute with a standard deviation of 4 43 This may be compared with the oxygen consumption of 13 soldiers recently studied in this laboratory who walked at 3 5 miles per hour on a 10 percent grade on a motor driven treadmill The mean oxygen consumption was 29 45cc per kilogram per minute with a standard deviation of 1 05 The variability in walking is clearly much smaller than found in running

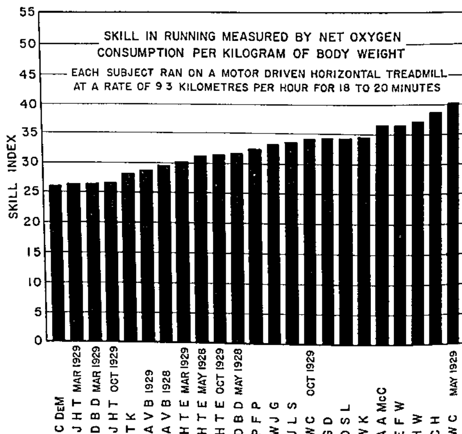


Fig 8 3 *The net oxygen consumption, corrected for basal metabolic requirements in cc per kilogram of body weight of 12 men running on a motor driven treadmill Data of Dill, Talbott, and Edwards* (28)

The individual data of Dill, Talbott, and Edwards is presented in Fig 8 3 In addition to the 10 men who comprised the main body of this study, data on a champion marathon runner (C DeM) and a college miler (T K) are included for comparison Observations before and after some months of running several times a week on the treadmill are also presented The improvement in skill with repetitive practice sessions is well illustrated by the gains made by subject W C It is of interest that C De used 27 percent less oxygen per minute to move one kilogram one kilometer than W C who

was the least skillful man in the group when his oxygen consumption was first measured

The largest individual differences in the cost of doing a specific task can be found in the more complex activities with which the participant may be completely unfamiliar at the time of the first contact with the sport A good example of this is swimming Karpovich and Millman (48) found that it cost a good swimmer 10 to 15 calories per minute to swim the crawl at a rate of 2 to 3 feet per second This may be compared to the 22, 36, 44, and 65 calories per minute that it cost four untrained swimmers to swim the crawl at approximately the same rate

It is common knowledge that repetition improves performance In the complex unfamiliar tasks, much of this improvement comes as the result of reducing the oxygen cost of work, i e, improving the skill with which a task is performed The coach can assist his athletes in training by thinking of ways and means of reducing unnecessary motions to a minimum

On the other hand, repetition of a task that is already familiar and that has been practiced a great deal does not result in any important improvement in the oxygen cost of work An example of this is found in treadmill walking Repeated bouts of grade walking on the treadmill show minimal (0 to 2 percent, Erickson

Neufeld, 54) improvemen

provement that Knehr, *et a* [illegible]

to treadmill construction The treadmill used at the Laboratory of Physiological Hygiene (Erickson, *et al*) was equipped with a rubber belt which had a corrugated surface and ran on a smooth wooden slipway which supported the weight of the subject The Fatigue Laboratory treadmill was fitted with a leather belt which had a smooth surface and ran on a bed of supporting rollers It seems quite possible that the Fatigue Laboratory treadmill was more difficult to walk on due to the slippery surface and slight irregularities produced by the rollers As a result, this task may not have been one with which the subjects were completely familiar

3 The Mechanical Efficiency of Work

The most precise method of expressing the ability to perform a task with economy of energy expenditure is to calculate the mechanical efficiency This is usually done with some variant of the following equation

$$\text{M E (in percent)} = \frac{(\text{external work accomplished in kilo calories}) \times 100}{\text{net energy used in kilo calories}}$$

mate of the external work accomplished by the individual Once the external work has been measured the mechanical efficiency can be found after con

verting numerator and denominator to similar energy units Measuring the external work is sometimes extremely difficult or impossible Holding a weight out at arm's length without moving it is a task that requires energy and is rapidly tiring but in which the individual does no external work Lifting a weight from the floor to a shelf allows precise determination of the external work in terms of foot pounds A convenient apparatus for the determination of external work is the bicycle ergometer Here the bicyclist can be made to drive an electric generator with only a small loss of energy in the heat of friction in the generator driving apparatus

Estimates of the mechanical efficiency of work in man for a variety of tasks are presented in Table 8 2 The mechanical efficiency of a well trained

TABLE 8 2 The Mechanical Efficiency of a Variety of Tasks Performed by Man

Conditions and Method of Calculation	Rate of Work O_2 Intake Liters/Min	Mechanical Efficiency Percent	Refs
Riding bicycle ergometer		23	(25)
Grade walking treadmill	2 0	17–19	(31)
Grade walking treadmill corrected for horiz energy	2 0	31 2	(31)
Hill climbing	2 2	19–23	(30)
Hill climbing corrected for horiz energy	2 2	28–32	(30)
Running on level		22 3	(32)
Swimming underwater	1 1	2–8	(33)
Swimming underwater	2 0	3–5	(34)
Swimming surface		0 5–2 2	(49)

bicycle rider is presented in the table In grade walking on the treadmill, the external work is calculated as the vertical lift of the body weight This results in rather low efficiencies which are believed to be due to the failure to account for the external work accomplished in the horizontal vector of the locomotion A number of authors have attempted to correct for this by measuring the cost of horizontal locomotion at the same speed This energy cost is now subtracted from the total produced by grade walking and the difference is attributed to the cost of the vertical lift This calculation increases the apparent mechanical efficiency to the level of 30 percent to 35 percent It is believed that this method assigns too much energy to forward locomotion It appears likely that some of the energy of forward locomotion is converted to lifting work by body mechanics A proper analysis of this problem has never been attempted

Durnin (30) studied experienced mountain climbers carrying packs up a slope which rose 1 foot in every 5 7 feet of linear distance on the slope The natural pace of each climber was carefully determined before the experi

ment The linear speed was 1 8 miles per hour The efficiency was very high, a number of values of 23 percent were found and one of 26 percent was recorded It is likely that the very high efficiencies were attained because the investigators allowed experienced mountain climbers to select their natural gait Other speeds might well result in lower values of efficiency The work of Fenn (32) is interesting because he studied men running on a level track and made estimates of (1) the kinetic energy in arms and legs, (2) the work of decelerating arms and legs, (3) the work the subject did against gravity, (4) work against wind resistance, (5) heat lost in friction between foot and ground When these values were added up, Fenn found a value for efficiency that was very close to that found in other types of work It is unfortunate that an analysis of this kind is so time consuming since careful comparison of the trained with the untrained individuals should give coaches hints in how to teach the less skillful runners to improve their efficiency

To calculate the efficiency of swimming one must determine the resistance of the water to the motion of the body through it This has been done by towing the swimmer through the water and measuring the force with a spring Or the subject is asked to swim and is held back by a rope fitted with a spring scale Underwater studies have been carried out in a hydraulic laboratory where the speed of moving water can be controlled experimentally The measurements of drag are perhaps not completely accurate (alternative methods seldom give precisely the same figure) but there can be little doubt that swimming is a very inefficient method of locomotion Studies on underwater swimming in the hydraulics laboratory quickly demonstrate inefficient methods of swimming underwater

This discussion has been confined to the immediate mechanical efficiency of work Here the investigator restricts his observations to the time the work was being done and the period of recovery from it However a little broader view changes our picture of the efficiency of the human machine Take for example the mountain climber who is faced with a climb that will take three days The mountain climber must remember that the human machine cannot work 24 hours a day and must spend time preparing and eating meals and sleeping The efficiency of the complete operation must not only be calculated in terms of the total energy derived from O_2 intake during climbing but should also include the complete cost of the overhead, i e the 24 hour energy expenditure From this point of view, the efficiency of the human machine is low, less than 1 percent

4 The Relationship of Speed and Mass to the Mechanical Efficiency of Muscular Work

Table 8 2 gives a value for the mechanical efficiency of grade walking corrected for the horizontal energy expenditure as 31 2 percent This value was used since it was that obtained when the men were using approximately

2 liters of oxygen a minute and is comparable to the other figures in the table However, it should be recognized that the speed of the treadmill belt had a marked effect on the mechanical efficiency For example, subject D. M had an efficiency of 28 3 percent at 2 5 miles per hour on a 5 percent grade At 3 miles per hour on the same grade the efficiency was 37 6, at 3 5 m p h, 40 3, and at 4 m p h, 26 6 The subject of this experiment increased the number of steps from 88 per minute at 2 5 miles per hour to 116 per minute at 4 0 miles per hour Then the speed with which the legs and therefore the muscles were moving increased substantially over the range of treadmill belt speed studied The data indicate that mechanical efficiency was maximal at some intermediate speeds and low in both slow speeds and fast speeds This observation is by no means new Lupton's observations (47) on the effect of speed of climbing stairs on the mechanical efficiency is familiar to anyone who has looked at a text on muscle physiology It is generally believed that the performance of a task at very slow or very rapid rates involves the use of accessory muscles and therefore would, because of this fact, have a low mechanical efficiency However, certain properties of isolated muscle described by A V Hill will also account in part for the relationship between speed and efficiency described above

In some of his early investigations of the capacity of muscle to perform work, Hill showed that the human arm muscles can perform more work when pulling against a large mass than against a small In the particular experimental set up that Hill used, speed of contraction turned out to be the critical factor In order to attain the maximal realizable work the time of shortening must be long enough to allow the liberation of energy required to move large loads Indeed, this relationship is a precise one that can be expressed mathematically for both frog muscle (41) and human voluntary muscles (42,14) The shortening of a muscle against a constant force can be described by the following equation

(1) $$(P + a)\ (V + b) = \text{constant}$$

where P = force and V = velocity and a and b are constants In the case of muscular contractions in the human arm, the work done does not achieve its maximal value until it is opposed by a mass which is large enough to require between 2 and 3 seconds for muscular contraction to take place Equation One has a bearing on the mechanical efficiency of the muscle Hill (41,15) has examined this problem in the isolated frog's muscle In this situation Equation One can be written

(2) $$(P + a)\ (V + b) = (P_o + a)b$$

where P_o is the full isometric tension

The total energy produced during a contraction of an isolated frog's muscle can be described by the equation

(3) $$H = aX + KT$$

where X is the distance the muscle shortens, a is defined as in Equation One, T the time of contraction, and K is a constant relating time of contraction to the heat given off during the maintenance of contraction

The work done in shortening is

$$(4) \qquad W = PX$$

The general equation for efficiency is

$$(5) \qquad E = \frac{W}{H + W}$$

which can be written

$$(6) \qquad E = \frac{PX}{(P + a)\ X + KT}$$

The student will note that the definition of heat given off by a muscular contraction in the above equations omits any reference to the heat of recovery This is valid since the heat of recovery is equal to that of contraction to divide

optimal point relative to both speed and load For example, with a high velocity of shortening, the term KT is small but with a rapid contraction P is also small and the efficiency is low When the muscle moves slowly P is large as is T and again the efficiency is low The maximal efficiency lies somewhere between The actual relationships to speed and load have been worked out in the laboratory on isolated frog muscle and conform to theory (41,16) The constant b has the dimensions of velocity which is expressed as contraction per muscle length per second This constant is, of course, related to efficiency In the frog, b is one third of the muscle length per second The optimal load is expressed in terms of fractions of the full isometric tensions In man, Hill has estimated that the maximal efficiency should occur when the muscle is lifting one half the maximal load and shortening at a rate that is one sixth of the maximum speed under zero load (42)

This picture conforms to the observations presented at the beginning of this section on the effects of speed on the mechanical efficiency of grade walking and stair climbing *Caution should always be used in applying results* obtained on isolated frog muscle to man In this case there appears to be good reason for believing that the optimal speed for mechanical efficiency is determined in part by the relationships between speed and mass described by Hill

5 The Relationship Between Mechanical Efficiency and Diet

Krogh and Lindhardt (56) were the first to point out that the mechanical efficiency of work as measured on the bicycle ergometer is higher when the

subjects have been fed on a high carbohydrate diet for some days as compared to the same subjects existing on a high fat diet The same conclusion was reached when the work performance of men existing solely on water was studied by Henschel, Taylor, and Keys (37) Fig 8 4 shows that the mechanical efficiency decreased 7 percent of the initial figure when the apparent amount of fat oxidized during work increased from 50 percent to

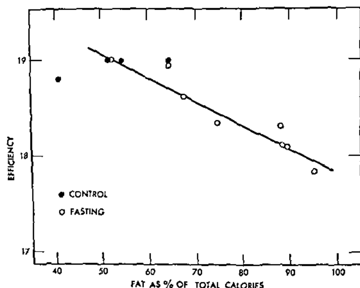


Fig 8 4 *The relationship of mechanical efficiency of work in grade walking expressed in percent to the percent of total calories burned as fat during acute starvation with work Data of Henschel Taylor, and Keys* (37)

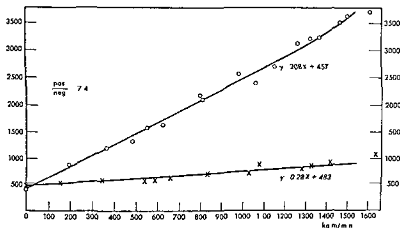
over 90 percent of the total calories expended This is related to the increase in energy necessary to oxidize fat But a low blood sugar has an important effect on efficiency of certain kinds of complex activities Thus in acute starvation when the blood sugar fell below 70 mgms per 100 ml of blood, the speed of small hand movements decreased and a correlation coefficient of 0 65 between blood sugar concentration and speed was found which was significantly different from zero (35)

A number of investigators have suggested that maintenance of the blood sugar level above the normal level is useful in work performance, but these claims have never been substantiated

The relationship between blood sugar levels, diet, and performance is a subject that is treated fully elsewhere in this monograph, but it may be worth mentioning that the relationship between blood sugar and psychomotor measures of speed and coordination is an area that deserves more careful study

6 The Physiological Cost of Negative Work

When a 10 kilogram weight is lifted vertically for 10 meters, 10 kilogram meters of physical work have been accomplished and the weight has acquired the same amount of potential energy If the weight is returned to the spot from which the lift was started, the balance of work accomplishment is zero If the same weight is lifted by human muscles, work is accomplished against gravity by contracting muscles If the weight is lowered slowly by man, work



a man bi
ted against
ussen (4)

is done against gravity, but this time the muscles are first contracted and then allowed to stretch It is common experience that moving a weight from a shelf to the floor is less fatiguing than the reverse operation This suggests that energy is absorbed by muscles which are stretched by a force from its contracted position

When a muscle exerts a force P and contracts a distance X it has done PX amount of positive work If a muscle exerts the force P and is stretched a distance X during contraction, it is said *to have done PX amount of negative work*

Abbott, Aubert, and Hill (1) studied the energy relationships which take place when an isolated muscle maintained in isometric contraction is stretched These investigators found that excess heat was produced during stretching but that this did not account for all the work that was done Roughly one half of the energy necessary to stretch the muscle appeared to have been absorbed by it If the muscle was stretched during relaxation all the energy used in the stretch appeared as heat These authors speculated that the chemical mechanisms which drive the contraction of the muscle are reversibly coupled to the contractile elements during stimulation and

that energy is absorbed by a chemical mechanism Alternative mechanisms which do not postulate this reversible coupling have been offered by Asmussen (4,19)

Negative work has been studied in man by Abbott, *et al* (2) and by As

studied a man riding a bicycle on the treadmill both uphill and downhill In Fig 8 5 the subject pedaled at 8 6 km /hr which required 135 revolutions per minute The ratio, cost of positive work/cost of negative work, was shown to be 7 4 Other experiments showed that the ratio could vary between three and nine Since the muscle tension pedaling backwards downhill is the same as that pedaling up the same grade, it can be concluded that muscles can produce tension three to nine times more cheaply when they are doing negative work than when they are performing positive work

FACTORS AFFECTING THE OXYGEN INTAKE PART TWO MAXIMAL OR ANAEROBIC WORK

In an earlier section this type of work was defined as that in which the oxygen cost per minute at all times exceeds the actual oxygen intake Work of this kind cannot be continued indefinitely since there is a limit to the amount of anaerobic energy a given individual is willing to employ

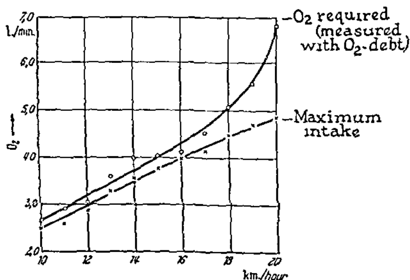


FIG 8 6 *The oxygen intake and requirement in liters per minute plotted against speed Data of Christensen and Hogberg (22), as modified by Karpovich (47)*

From the point of view of oxygen consumption, maximal work is characterized by an oxygen intake close to the maximum for the working conditions under study and by a sizeable oxygen debt This kind of work is, of course, accompanied by marked changes in the composition of the blood, the expired air, and by pulse rates which are close to maximal In this section the oxygen intake during work and recovery will be examined and in addition metabolic and cardiovascular correlates will be considered

The relationship between work intensity and oxygen consumption on the one hand, and oxygen requirement of work on the other, is presented in Fig 8 6 The oxygen requirement here is calculated as the total oxygen consumed in excess of basal metabolic requirements for the complete work task (in liters) plus the oxygen debt in liters divided by the time of work (in minutes) It is clear that under aerobic conditions in which a true steady state exists, the oxygen intake during work is related by a constant to the oxygen requirement In this range of work conditions the oxygen debt represents the difference between oxygen requirement and intake which occurs during the initial adjustment of the cardiovascular system to the demands of the work When the oxygen requirement exceeds the intake at all phases of the work period, the oxygen debt ceases to have a linear relationship to the oxygen intake and increases rapidly with an increase in the work rate

1 ([illegible] ING ANAEROBIC WORK THE MAXIMAL [illegible]

[illegible] of work in his study of maximal wo[illegible] alking up a steep grade on a motor driven treadmi[illegible] on the level or on a grade, usually on a motor driven treadmill, (3) pedaling a bicycle ergometer These tasks all have in common the use of a large fraction of the musculature of the body and certain dynamic aspects which lend themselves to all-out performance Unless otherwise noted, the following discussion will be based on observations obtained during one of these three tasks The details are not strictly interchangeable but the general principles appear to be so

The time characteristics of the oxygen intake during maximal work can be seen in Fig 8 7 taken from the work of Robinson (71) The figure shows oxygen intake for each minute of a five minute exhausting run for 10 groups of males of different age The oxygen intake is expressed as percent of the largest intake recorded in the course of the run With the exception of the very young and the men past middle age, the oxygen intake has reached its maximal level by the second minute of running

The conditions under which a maximal oxygen intake can be achieved have been studied by selecting a standard time of running which has [illegible] three minutes in one laboratory (76) and five minutes in another (7), [illegible]

oxygen consumption is determined at some time after an apparent steady state with regard to oxygen intake The test procedure is repeated for several increasing work loads until a further increase in the work load fails to result in a further increase in oxygen consumption This oxygen intake is designated the maximal oxygen consumption This gives a definition of maximal oxygen intake which is independent of the motivation of the subject

The effect of increasing the work load on the O_2 intake in separate experi

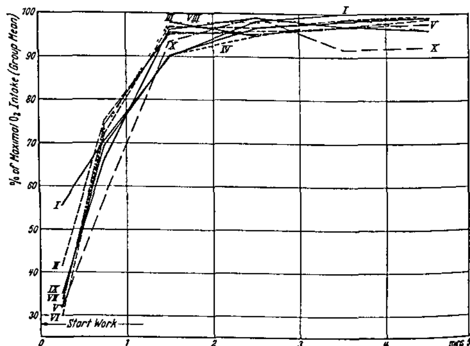


FIG 8 7 *The oxygen intake expressed as percent of the maximal O_2 intake plotted against time in minutes of running on a motor driven treadmill at grades and speeds suitable to produce a minimal oxygen intake Each line represents the mean of a group of men of the same decade in age Mean ages of the groups I, IV and X are 6 0, 17 4 and 75 0 years Data of Robinson (71)*

ments is illustrated in Fig 8 8 Here the work load has been increased by increasing the speed of the treadmill while the grade was held constant on the one hand, and increasing the grade while the speed was held constant on the other Experiments of this kind showed that more men can attain a maximal O_2 intake plateau if the speed is held constant and the grade is increased than if the grade is held constant

it applies to the particular conditions studied, i e, the type of work task and the conditions used to increase the metabolic rate A demonstration of

this is found in the fact that there are conditions under which a maximal oxygen intake cannot be elicited It has been mentioned that some men will show a plateau of O_2 intake with increasing work load by increasing the grade of a motor driven treadmill while they cannot demonstrate this plateau when the work load is increased by increasing the speed of running Furthermore it appears that if one increases the speed or the grade every minute during the same run until exhaustion occurs, a maximal oxygen intake is seldom demonstrated (75)

Another factor appears to be the quantity of muscle employed to perform the task One of the first demonstrations of this was by Christensen and Hogberg (23) who showed that cross-country skiing elicits a higher maximal oxygen intake that does running This observation was confirmed by Taylor, Buskirk, and Henschel (76) who showed that if the conditions of treadmill running which would elicit the maximal oxygen intake were determined and then a simultaneous task employing the arms was superimposed upon these conditions, the "maximal oxygen intake" was increased by approximately 7 percent

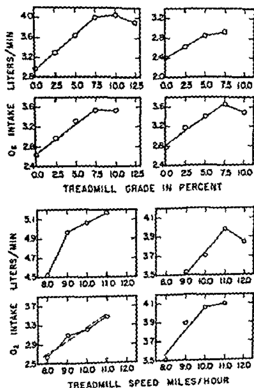


FIG 8 8 *The oxygen intake in liters per minute plotted against an increasing work load each point represents the* O_2 *intake taken between 1 minute and 45 seconds of a separate run In the upper four figures, the speed was held constant at 7 m p h and the grade was varied In the lower four figures the grade was held constant and the speed was varied Each figure represents a different individual Data of Taylor* et al (76)

... a large ... will have ... man with a small bony frame and small muscles ... n, some reference point must be used which will account for ... in size of the two men The simplest way to do this is to use body weight as a reference point The maximal oxygen intake expressed as cc per kilogram of body weight provides a

direct measure of the amount of oxidative energy available to move one kilogram of body weight from one place to another over the ground

The physiological factors limiting the maximal oxygen intake have been recognized for some time They can be considered under three headings (1) respiration, (2) cardiac performance, (3) peripheral factors

2 Respiration as a Factor Limiting the Maximal Oxygen Intake

The respiratory factors do not seem to offer any serious limitation in the presence of normal lung tissue and unimpaired respiratory mechanics Respiratory function and physical activity have been discussed elsewhere in this monograph so this is not the place for an extended discussion Briefly the few measurements of diffusion coefficient during work (57,70,74) (i e, DO_2 = the number of milliliters of oxygen crossing the pulmonary membrane per minute in response to a mean pressure gradient of 1 mm Hg) indicate that the DO_2 increases with exercise It is generally believed that the diffusion capacity of the lungs is adequate to oxygenate the arterial blood at high levels of performance This conclusion is well documented by the work of Mitchell, *et al* (62) who showed that the saturation of the arterial blood is well over 90 percent when the maximal oxygen intake has been reached by normal young men It should be recognized that reduced arterial saturations have been observed during exercise This is usually considered to be the result of poor distribution of blood and air in the lungs which produce physiological shunts More work must be done in this area However, Mitchell s results indicate that under conditions of the maximal oxygen determination, the arterial blood is adequately saturated and is not a limiting factor in the maximal oxygen intake under the restricted conditions discussed here (7,76) It is clear that more work needs to be done in this area to explain some of the contradictions which are currently present in the literature

At high rates of ventilation, the respiratory muscles use a measurable amount of oxygen Nielsen (65,24) has reported that in maximal work requiring 116 liters of ventilation and 4 59 liters of oxygen a minute, the respiratory muscles used 406 ml of oxygen per minute Otis (66) has pointed out that this figure might be as much as 1100 cc per minute Examination of the factors affecting the cost of breathing in voluntary hyperventilation experiments at rest reveals two important factors in the cost of breathing The first is the elastic work of moving the chest wall, expanding the lung and so forth This work is decreased as the breathing rate increases But as the breathing rate increases, the acceleration of air during inspiration and expiration as well as the peak rates of air flow increase rapidly Nonelastic work then increases with increasing rates This and the fact that breathing which is carried on at too rapid rates results in poor ventilation of the alveoli places an upper limit on the rate of respiration during severe exercise

Estimations have been made of the optimal rate of breathing for a given

ventilation on three individuals at two rates of ventilation which are found during exercise (12) The optimal rate at 40 liters of ventilation per minute was estimated at 23 breaths per minute while that at 100 liters of ventilation per minute was estimated to be 40 breaths per minute These optimal rates of breathing are not far removed from that found in men performing work requiring 40 and 100 liters of pulmonary ventilation The data suggest that the energy cost of breathing during maximal work is not likely to be above 500 cc of oxygen a minute Otis (66) has calculated that a ventilation of 140 liters a minute is probably the upper line beyond which the ever increasing cost of ventilation will make unprofitable the resulting increment of oxygen consumption left over for physical work This prediction is interesting when one considers that during the maximal oxygen procedure respiratory volumes vary between 90 and 140 liters of air a minute All this bolsters the concept that the cost of pulmonary ventilation is not an important limiting factor in the maximal oxygen intake However, it must be recognized that this is not an area which has been intensely cultivated and much work remains to be done relating the cost of respiration to rates and volumes observed during work in the same individual and in studying the effects of age, training, etc

3 Cardiac Output as a Factor Limiting the Maximal Oxygen Intake

In order to move 4 to 5 liters of oxygen a minute to working muscles, a very large cardiac output is required If one assumes an arteriovenous difference of 75 percent of oxygen capacity of 20 ml per 100 ml blood, then 5 − 150 gives a cardiac output of 33 liters per minute

The cardiac output during exhausting work has been studied with the acetylene method (6,18), with the dye injection method (62), and with both methods (5) simultaneously Some of the important physiological characteristics are presented in Table 8 3 The data in the first two lines

Table 8 3 Some Physiological Values Found in Blood and Circulation During Heavy Work

Ref	Max O_2 Intake L/Min	Cardiac Output L/Min	Total A V O_2 Diff cc /L	Muscle A V O_2 Diff cc /L	Stroke Vol cc	Pulse Rate Beats/Min
Asmussen and Nielsen	3 0	22	150	180	120	180
Christensen	3 9	33	120	130	200	170
Mitchell, *et al*	3 2	23	143		125	187
	±0 46	±5 5	±25		±25	±10

Note Asmussen and Nielsen and Christensen studied one subject each Mitchell *et al*, studied 15

of this table are selected from two individuals who are in quite different status of training Christensen's subject was a man who was in excellent physical condition while the subject studied by Asmussen and Nielsen (6) was not in good physical condition In general it is believed that the higher the maximal oxygen intake, the larger the cardiac output The data suggest, and there is much indirect evidence to support, the concept that the well trained man increases his stroke volume more than the untrained man and that the trained man has a maximal pulse rate which is lower but not a great deal lower than the untrained man The cardiac output of the trained individual is larger per liter of oxygen moved to the muscles, the arterio venous difference is smaller in the well trained individual The arterio-venous oxygen difference for blood running through working muscle was calculated by Asmussen and Nielsen (6) on the assumption that the irrigation and O_2 uptake of the remaining organs is the same during rest as in the working position The arteriovenous difference of blood flowing through muscles in Asmussen's untrained subject is larger than the observed value for the overall circulation This leads to the conclusion that in the untrained individual the arteriovenous oxygen difference of blood flowing through the working muscles is very nearly equal to the oxygen capacity of the blood

Mitchell, *et al* (62) used the dye injection method to study the cardiac output in young men during actual maximal oxygen determination The data obtained are presented in Table 8 3 These men were not in a high state of physical training and it is interesting to note that the group mean of the overall arteriovenous oxygen difference is close to that found by Asmussen and Nielsen It follows then that the arteriovenous oxygen difference of blood running through the working muscles in the group studied by Mitchell, *et al* was close to the oxygen capacity of the blood This group contained 15 individuals and is large enough so that one might hazard a generalization that in the untrained individual the arteriovenous oxygen difference of the blood flowing through the working muscles is close to the oxygen capacity of the blood when work is being performed at a rate which will elicit a maximal oxygen intake

4 Peripheral Factors Limiting the Maximal Oxygen Intake

The size of the capillary bed or quantity of blood running through the muscles has been mentioned by a number of investigators as an important limiting factor in the maximal oxygen intake The size of the capillary bed and the arterial tree leading to it will, of course, have a profound influence in the quantity of blood returned to the right heart In submaximal states there is an elegant balance between cardiac output, blood pressure, the size of the vessels in the muscles, and the venous return However, when the point is reached at which the system will no longer increase blood flow and oxygen delivery to the muscles, the old dilemma of identifying the limiting factor presents itself Is this limited by the capacity of the heart to pump

blood? Or is the size of the arterial and capillary bed in the muscles the limiting factor? Or is the cardiac output limited by some peripheral factor which is unrelated to the *dimensions* of the peripheral vascular bed? This question cannot be resolved in as satisfactory a way as we would like but evidence is accumulating which favors the concept that the dimensions of the peripheral vascular bed are the most important of the several possibilities Evidence in support of this view is to be found in the work of Christensen (19) who found that a man doing work with his arms had a maximal oxygen

intake of 4 64 liters/min bicycling, 4 57 liters per minute running but when skiing (with poles) his intake rose to 5 24 liters per minute Bicycling and running use the leg and lower back muscles while in skiing the additional muscles of the arms and back are used to manipulate the ski poles Taylor Buskirk, and Henschel arranged a hand ergometer over a treadmill and performed arm work while running on the treadmill at speeds and grades which elicited a maximal oxygen intake It was found that the additional work increased the maximal oxygen intake by 200 to 250 cc per minute This evidence leaves us with a strong presumption that if after a maximal oxygen intake under a given set of conditions is reached new muscles are grouped into play the heart can increase the cardiac output

It has been pointed out above that the maximal oxygen intake per kilogram of body *weight is* a good measure of the oxidative energy available for moving a man from place to place So we may regard this figure as a good fitness index which is related to the capacity of an individual to run a mile race On the other hand if one is interested in evaluating the performance of the cardiovascular system and in comparing one individual with another then the ideal reference point would be the weight of the active muscles Estimates of the weight of the active muscles for any specific task are extremely difficult However one can estimate the quantity of active tissue which *consists principally* of muscles or the weight of the fat free tissue which does not include a correction for the weight of the bones (50) If one selects a task which employs a relatively constant fraction of the total *muscle mass in different individuals then the maximal oxygen intake per* kilogram of active tissue should constitute a good basis for comparing the cardiovascular performance of one individual with another Evidence in support of this can be found in the work of Buskirk and Taylor (17) The correlation coefficient between fat free body weight and maximal oxygen intake was found to be 0 85 in the group which was not involved in systemic physical activity The correlation coefficient with body weight was 0 63 The difference in correlation coefficients can be accounted for by the wide variation in the proportion of adipose *tissue* which was observed among the individuals The correlation between maximal oxygen intake and active

tissue" was 0 91 But it is not believed that any significant difference exists between this figure and that found for fat free body weight This result is consistent with data of Von Dobeln (79) who reported a correlation coefficient of 0 75 between weight adipose tissue and maximal oxygen intake The data in Fig 8 9 show that athletes in good condition have a larger maximal oxygen intake per kilogram of fat free weight than their more sedentary contemporaries It will be remembered that young men undergoing conditioning programs show an increase in the maximal oxygen intake of from 5 to 15 percent (54 72) From this we can conclude that the difference between the sedentary individual and his physically active contemporary is in part at least due to an improved cardiovascular performance, which may be related to the fact that the well trained muscles have a larger vascularization than the untrained muscle

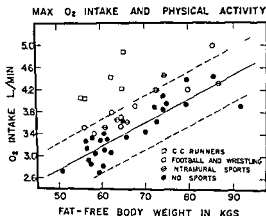


FIG 8 9 *The relationship between maximal oxygen intake in liters per minute and fat free body weight in kilograms The regression line was calculated from the men who took part in no systematic sports The dotted lines represent two standard deviations Data of Buskirk and Taylor (17)*

The high correlation coefficient between 'active tissue" and maximal oxygen intake is consistent with, but does not prove a causal relationship between, the mass of active muscle and cardiac output or the maximal oxygen intake It is not, as has been suggested, evidence that the cardiac output is unimportant as a limiting factor, but rather that the two vari abl...

... by the other (muscle mass)

A second peripheral factor of importance is that of the total amount of circulating hemoglobin Astrand (7), employing a method developed by Sjostrand (52,30), studied the relationship of total hemoglobin to the maximal oxygen intake in 43 males (age 7–30 years) and 51 females (age 7–31 years) The ...

... ence point for the prediction of a standard maximal oxygen intake which is independent of age, sex, body size, degree of obesity, and other variables However, it is not likely that the total circulating hemoglobin is a limiting

factor which has the importance indicated by the correlation coefficient Astrand found a very high correlation between circulating hemoglobin and body weight Furthermore the correlation coefficient between body weight and maximal oxygen intake in males irrespective of age was 0 98 Buskirk and Taylor (17) and Von Dobeln (79) attempted to assess the role of circulating hemoglobin which is independent of other variables Buskirk and Taylor found correlation coefficients between fat free body mass and circulating hemoglobin and maximal oxygen intake and circulatory hemoglobin to be of the same order of magnitude Von Dobeln calculated multiple correlation coefficients and found that the correlation coefficient between maximal oxygen intake and total hemoglobin was 0 25 when other factors such as fat free body mass were taken into account

It has been pointed out that the maximal oxygen intake of individual men may be estimated from the pulse rate at submaximal rates A nomogram has been prepared and put forth with which to predict the maximal oxygen intake (9)

The oxygen intake may be related to circulatory factors by the following equation

$$O_2 \text{ intake} = (\text{pulse rate}) \ (\text{stroke volume}) \ (A - VO_2 \text{ difference})$$

where the oxygen intake is expressed as ml of oxygen per minute, pulse rate in beats per minute, the stroke volume in liters and the $A - VO_2$ difference in ml per liter of blood It has been contended by Wyndham and Ward (80) that as the maximal O_2 intake is reached, the stroke volume and the arteriovenous difference have reached their maximum value and any further increase in O_2 will be due to an increase in pulse rate Finally, the variability of the maximal pulse rate within a group of individuals is relatively small Berggren and Christensen (14) have shown that oxygen consumption and pulse rate are rectilinearly related Knowing the approximate maximal heart rate, one can make observations of heart rate at two or three submaximal levels and then extrapolate to the maximal value Wyndham and Ward (80) have done this and find that this is a useful procedure that readily distinguishes between cardiacs and normals There are a number of situations where it is clear that a measurement of the submaximal pulse at a single work rate will not allow one to predict the maximal oxygen intake with a nomograph relating submaximal pulse rate with the maximal oxygen intake prepared on normal young men Among these conditions, one may mention (76) (1) men in the older age groups (2) semistarvation, (3) starvation acidosis However, the possibility exists that the extrapolation technique would yield better results and would be useful in what are today exceptions to a general rule

5 Concentration of Hemoglobin

The above considerations coupled with Equation One (p 136) make it quite clear that in the presence of an anemia the concentration of hemoglo-

bin can have an important effect on the maximal oxygen intake This will occur as soon as the concentration of hemoglobin has fallen enough to re duce the arteriovenous oxygen difference under the conditions of heavy work Data bearing directly on this question are lacking

6 PHYSIOLOGICAL CONDITIONS WHICH INFLUENCE THE MAXIMAL OXYGEN INTAKE

There are a number of physiological conditions which affect the maximal oxygen intake A bout of exercises or a 'warm up' produces an increase in the maximal oxygen *intake of roughly 5 percent Fifteen minutes of walking* at 3 5 miles an hour on a 10 percent grade is an adequate exercise period for this effect Mitchell, *et al* (62) have found that after a 'warm up' has been achieved maximal oxygen determinations can be repeated in twenty minutes without affecting their reliability It is interesting to note that a small meal has no demonstrable effect on the maximal oxygen intake (76) The effects of a large meal have not been tested An elevation of the atmospheric tem perature from 78° to 90°F results in a small decrease The details of the ef fects of wide range atmospheric conditions have not been worked out

The effects of physical conditioning have been mentioned above If de conditioning is brought about by placing an otherwise healthy man in bed for three weeks, the maximal oxygen intake is decreased by roughly 15 per cent (77)

Deconditioning as the result of malaria resulted in a slightly larger decline (18 percent) of the maximal oxygen intake (36) Acute starvation with a loss of 7 percent of body weight dehydration and acidosis produces no decline per kilo of body weight or, expressed in another way, a decline which is proportional to body weight Semistarvation results in a decrease which is proportional to the body weight until a weight loss of 10 percent is reached Some time between a 10 percent and a 17 percent loss of weight the decline of the maximal oxygen intake is markedly increased and a substantial loss of maximal oxygen intake and capacity for anaerobic work results (51,78) It should be noted that the *most important* change occurring here is a shrink age of the muscle mass If a man is placed on short rations of both water and food and forced to work, weight is decreased more rapidly than the maximal oxygen intake and work performance is well maintained in the face of con siderable dehydration On the other hand, if dehydration is produced in unacclimatized men through excess sweating in a hot room, the loss of salt and extra cellular fluid produces circulatory inefficiency and a marked loss of maximal oxygen intake and work capacity (63)

Both Robinson (71) and Astrand (7) have studied the relationship be tween age and maximal oxygen intake The capacity to transport oxygen to the muscles increases with growth during childhood and reaches a peak in third decade (20 to 30 years of age), and then declines In the men studied by Robinson a decrease of 40 percent was observed in the seventh decade

7 The Oxygen Debt

Now that some of the factors have been explored which limit the capacity of the organism to deliver oxygen to the muscles, it is appropriate to examine the oxygen debt Almost any type of exercise that employs large muscle masses results in an oxygen debt In submaximal activities, this is the result of the fact that there is a circulatory lag during which time the circulation is increased to the point at which the oxygen requirement of the work is met by the oxygen delivered to the working muscles The oxygen debt of this type *increases in rectilinear fashion with increasing work intensity* There finally comes a time when the circulation no longer supplies oxygen at a rate which will meet the metabolic requirement of the working muscles Then it is found that substantial quantities of lactate appear in the blood and the oxygen debt is no longer related in linear manner to the work intensity but is rising rapidly toward an asymptote The total amount of energy available to the performer is the sum of the oxygen intake during work and recovery in excess of basal requirements[1] The oxygen debt has very definite limits so that anaerobic work cannot continue indefinitely On the other hand, it is doubtful if any athlete ever really uses up the chemical potential for piling up an oxygen debt The reasons why men stop exhausting work are complex and poorly understood It seems likely that reasons for stopping are only indirectly related to the oxygen debt One fact stands out the athlete is capable of producing a much larger oxygen debt than the nonathlete in poor physical condition (72)

The fact that large oxygen debts are accompanied by large lactate concentrations in the blood has led to a continuing interest in the relationship between lactate concentrations in the blood during recovery and the dimensions of the oxygen debt Hill, Long, and Lupton (43) were the first to relate the lactate concentrations in the blood during recovery to the O_2 debt

Margaria, Edwards, and Dill (61) studied the oxygen debt and blood composition of one man over a very wide range of work rates While the work rates were varied, all other physiological conditions were carefully standardized The subject reported in the morning in the basal state, rested for a half hour, ran exactly 10 minutes on the treadmill, then the oxygen debt was measured and the recovery blood samples for lactate determinations

[1] Exercise at an intensity which creates a large oxygen debt also produces an increase

mately 2.4 liters of oxygen could be accumulated without important quantities of lactic acid appearing in the blood This observation suggested that there was a certain amount of anaerobic energy that could be supplied by some mechanisms other than the breakdown of glycogen to lactic acid This conclusion was supported in turn by the fact originally noted by Hill that the oxygen debt is repaid at two rates of payment In the early phases of re

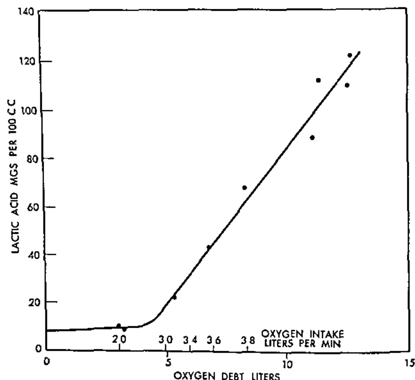


Fig 8 10 *The relationship of lactic acid concentration in the blood to oxygen debt in liters in one subject Data of Magaria, Edwards, and Dill* (61)

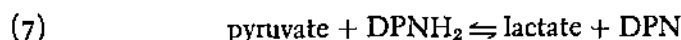
covery the oxygen debt is paid off rapidly, while the latter part is paid off slowly Margaria, Edwards, and Dill found that when they had accounted for the oxygen necessary to remove the lactate produced by exercise, the oxygen debt that was remaining was paid off at a rate that was 30 times as fast as that which appeared to account for the lactate removal This phase of the debt payment was a logarithmic function of time and was one half completed in 30 seconds and 98 percent completed in 3 minutes The slow component, also a logarithmic function of time, was one half completed in 15 minutes and 98 percent completed in one hour Thus the two rates of payment of the oxygen debt were accounted for on metabolic grounds Further

more the results placed considerable emphasis on sources of anaerobic energy other than the glycolysis of glycogen to lactic acid such as the release of energy from the splitting of high energy phosphate bonds in adenosine triphosphate, creatine phosphate, etc In addition, it provided evidence in support of the proposition that the concentration of lactate in the blood during recovery was a good measure of the size of the oxygen debt and the rate of removal of lactate from the blood was an accurate indicator of the rate of payment of the oxygen debt Much work on physical fitness and the effects of diet, training, etc that was done in the following years was based on this concept Furthermore the appearance of a lactate concentration in the blood that was greater than normal was widely interpreted as demonstrating the presence of tissue hypoxia

It is of considerable interest then that evidence has recently been brought forward to show that an increase in the blood lactate concentration cannot be rigidly interpreted as being the result of tissue hypoxia Evidence (44)

tions is there any evidence of the existence of tissue hypoxia Experience over a number of years has shown that in some situations blood pyruvate concentration increased with the lactate and in others it did not This leads to a consideration of the conditions under which lactate is produced and its relationship to pyruvate concentration

Lactate is formed from pyruvate in the body according to the following *nominal* equation



$$\text{pyruvate} + DPNH_2 \rightleftharpoons \text{lactate} + DPN \qquad (7)$$

where $DPNH_2$ represents reduced diphosphopyridine nucleotide and the reaction is catalyzed by an enzyme known as lactic dehydrogenase Where there is adequate oxygen present in the tissues, oxidation of carbohydrates proceeds in such a way that six carbon sugars are degraded to pyruvate with the loss of two H atoms These hydrogen atoms are carried by the cytochromes to the flavoproteins and then to the diphosphopyridine nucleotide where, if adequate oxygen is available, H_2O is formed to complete this stage in the oxidation process When the PO_2 of the tissue has fallen below a critical level then Equation One begins to operate and the reduced DPN is in effect oxidized by converting pyruvate to lactate The formation of lactate is

$$(\text{lactate}) = (\text{pyruvate}) \times K \frac{(DPNH_2)}{(DPN)} \qquad (8)$$

In this form it is clear that changes in the pyruvate concentration alone will result in a change in the lactate concentration The experiments of Huckabee (44) indicate that this can take place independently of a change in available tissue oxygen which is represented in Equation Eight by the expression $K \frac{(DPNH_2)}{(DPN)}$ Huckabee derived from Equation Eight an expression which allows the calculation of the fraction of the change in lactate concentrations which could be expected to be due to oxygen lack in the tissues All the required data are in molar concentrations of lactate and pyruvate determined before and after some experimental manipulation The equation for calculating the change in lactate concentration which may be properly ascribed to oxygen lack in the tissues follows

$$(9) \qquad XL = (L_n - L_o) - (P_n - P_o) \frac{(L_o)}{P_o}$$

Where L_n and L_o are experimental and control lactate concentrations, P_n and P_o, experimental and control concentrations of pyruvate, respectively, and XL (excess lactate) the fraction of the total concentration change of lactate which may be ascribed to tissue hypoxia Huckabee (44) has shown that this expression will show no excess lactate when the lactate concentration increases threefold as the result of hyperventilation, infusion of pyruvate, etc

This technique was applied by Huckabee (45) to exercise The total body water of each subject was determined and the total amount of lactate as well as total excess lactate was calculated from the change in concentration, on the assumption that lactate was evenly distributed through the body water A typical experiment is presented in Fig 8 11 The rate of exercise is not very intense (O_2 intake 2 1 liters per minute) and the observed oxygen debt is only a little over a liter A substantial increase in lactate concentration was noted which overestimated the observed O_2 debt The excess lactate concentration correctly predicted the observed O_2 debt It will be noted that the subject was asked to hyperventilate during recovery and that this maneuver resulted in some changes in the lactate concentrations which were not reflected in the estimated excess lactate concentration In other experiments evidence was presented suggesting that in well conditioned athletes, the lactate changes underestimated the oxygen debt Here, too, the excess lactate concentrations correctly estimated the oxygen debt Huckabee then has shown that even small oxygen debts are accompanied by an excess of lactate in the blood The concept that there was a large oxygen debt up to 2 5 liters that produced energy by some mechanism other than the lactate mechanism appears to be incorrect Huckabee points out that this O_2 debt resulting from the circulatory lag is not quite accounted for in his experiments and grants that a small amount of anaerobic energy might arise from sources other than the lactate mechanism This work has left us without any

metabolic explanation of the rapid and slow phase of oxygen debt payment Explanation of these phases will have to be sought elsewhere Furthermore a number of concepts and applications will have to be reexamined It has been shown that post exercise lactate concentrations differentiate well conditioned men from sedentary individuals (75 40) Will excess lactate concentrations improve or reduce the differentiation? The rate of disappearance of lactate during recovery after exhausting exercise has been used to show that

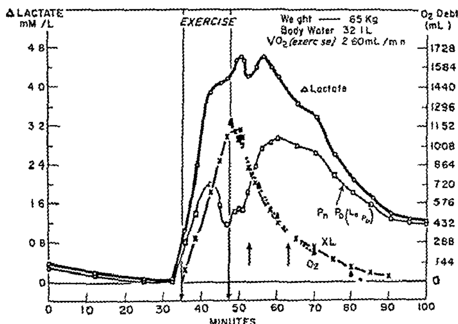


Fig 8 11 *The relationship between the change in lactate concentration the excess lactate and the oxygen debt Note that the body water of the subject has been determined and the O_2 debt equivalent of the total lactate and excess lactate calculated As a result all values of lactate can be read in both millimolar equivalents of lactate and milliliter equivalents of O_2 debt Data of Huckabee* (45)

recovery is improved by (1) oxygen administration (61) and (2) walking or jogging (64) Will these concepts remain after reexamination with the new procedures?

8 The Oxygen Cost of Maximal Work

Sargent (68) studied the oxygen cost of running 1 0 yards at various speeds between 1 and 9 yards per second He found that the energy expenditure of running this distance in a given time varied as the 3 8 power of the

speed and that the energy expenditure of running for a given time varied as the 2 8 power of the speed This means that as one approaches maximal performance any additional increment of speed will be very costly in terms of the oxygen required to perform it On the basis of this information, Hill pointed out that a runner would achieve the shortest time for running a given distance if he ran the whole race at a constant speed that was the fastest possible for him This advice was based in 1926 on the assumption that energy cost of running was independent of the type of energy mechanism (i e, aerobic or anaerobic) used by the runner However, Simonson and Sirkna (69) reported in 1934 that the anaerobic mechanisms were less efficient, i e, required more oxygen for a given amount of work accomplishment, than the aerobic mechanism This finding was not confirmed until 1946 and 1950 when both Swedish and Danish workers produced evidence in support of it (21,3) For example, Christensen and Hogberg studied an athlete who ran on the treadmill at 20 kilometers per hour for periods of 15 seconds to 3 5 minutes On each occasion the oxygen used during work as well as the oxygen consumed during recovery was measured These investigators found that in the very early phases of work the oxygen requirement

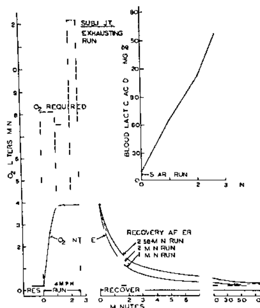


FIG 8 12 The oxygen requirement in liters and the oxygen intake during work and rest in runs at a constant speed of 14 miles per hour Three separate runs of 1 minute 2 minutes and 2 58 minutes were carried out The oxygen requirement for each period of the 2 58 minute run was calculated as follows

$$O_2\ req - \frac{O_2\ req\ \text{for next shorter run}}{\text{time of run} - \text{time of next shorter run}}$$

The culminated lactic acid and the rate of cumulation per minute is also shown Data of Robinson et al *(73)*

difference may be due to inefficient running during the first few seconds while the runner was getting into the stride which he found to be best for the speed but the differences are too large for this factor to be the sole cause

Robinson and his collaborators (73) investigated three men running to exhaustion in three minutes The cost of each minute was determined separately. The results obtained on one man are presented in Fig 8 12 It will be observed that the oxygen cost of the first minute was higher than in the second minute which is what Christensen and Hogberg observed but as the runner forced himself to exhaustion the oxygen requirement increased to a value that is 50 percent greater than that found in the first minute Two additional methods of running the same distance were studied by these authors. The men ran the first minute at a faster speed than average and then ran the last two minutes at a slower speed The third method was to run the first two minutes at a slower speed than the average and then the last minute at a faster speed. In one example, the subject required 24 7 liters of oxygen in excess of based requirements to run at a constant speed The run performed with a fast start required 25 9 liters per minute and the run with a slow start and a fast finish required 24 2 liters of oxygen Similar results were *obtained on the other subjects studied These data make it clear that* athletes should conserve their anaerobic reserves until late in the contest and that Hill's original hypothesis that the greatest speed for a given distance could be attained by running at a constant speed was incorrect

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Pulmonary Function in Relation to Exercise

SUMMARY

A graph is presented by means of which a number of factors of importance in the physiology of exercise can be visualized simultaneously These factors include oxygen consumption and carbon dioxide output, pulmonary ventilation and cardiac output, the oxygen cost of breathing and the oxygen cost of pumping blood, the partial pressure of carbon dioxide in alveolar gas and arterial blood, and the oxygen saturation of the mixed venous blood When certain reasonable assumptions are made, it becomes possible to show graphically the way in which all of these factors change with increasing grades of work under normal conditions and to mention a few adaptations to pathological states It seems doubtful that either pulmonary or cardiac function limits the ability of the well trained normal person to perform steady state exercise at sea level The control of breathing during exercise may involve, in addition to mechanisms setting the resting rate, a reflex stimulus dependent on mixed venous P_{CO_2} Hemodynamic measurements and basic hemodynamic principles point toward significant changes in the number of small pulmonary arteries and capillaries which are actively perfused during exercise Such changes are associated with changes in the distribution of blood and gas throughout the lungs, but ordinarily the changes in the oxygen and carbon dioxide tensions in the arterial blood are minor At sea level the diffusing capacity of the lungs is normally adequate to permit almost full saturation with oxygen of the blood leaving the lungs, even during very severe exercise

The load on the systems responsible for transporting respiratory gases between the ambient air and the tissues increases as the utilization of oxygen and the production of carbon dioxide increase during exercise It is convenient to consider the relationships between oxygen uptake, carbon dioxide

output, pulmonary ventilation, and cardiac output by reference to Fig 9 1

Here oxygen uptake and carbon dioxide output (V_{O_2} and V_{CO_2}) are plotted along the ordinate, pulmonary ventilation (V_E) is plotted along the abscissa in the left hand quadrant, and cardiac output ($\dot{Q}$) is plotted along the abscissa in the right hand quadrant The isopleths radiating from the

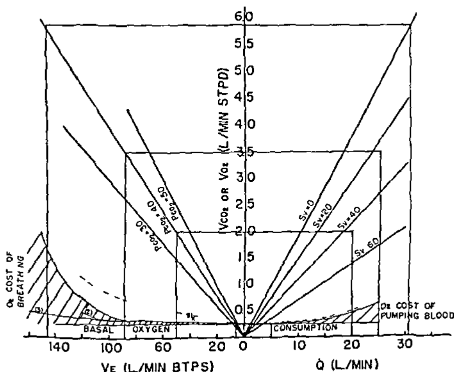


FIG 9 1 *Relationships between gas exchange, ventilation and blood flow Cross hatched areas represent oxygen cost of breathing (left) and oxygen cost of pumping blood (right)*
(1) indicates oxygen cost d by X) from data of Cournand Richards
(2) indicates oxygen cost , Westlake & Cherniack
(3) indicates oxygen cost of breathing from data of McKerrow and Otis The solid curve forming the upper boundary of the cross hatched area (left)

Isopleths represent alveolar or arterial P_{CO_2} (left) and mixed venous blood oxygen saturation (right)
Horizontal and vertical lines represent simultaneous relationships at different levels of exercise Topmost line highest recorded level of energy expenditure (skier Jernberg)

origin into the left hand quadrant indicate different levels of alveolar or arterial carbon dioxide tension (P_{CO_2}) and the isopleths in the right hand quadrant show different values for the oxygen saturation of mixed venous blood ($\bar{S}v$) The horizontal line at $V_{O_2} = 0.250$ liters per minute identifies basal oxygen consumption The cross hatched area in the left hand quadrant shows approximate values for the oxygen cost of breathing at different minute volumes and the cross hatched area in the right hand quadrant represents a crude estimate of the oxygen cost of pumping blood at different rates The broken curves in both the right and left quadrants represent the sum of the oxygen costs of maintaining body tissues, breathing, and pumping blood In constructing the graph, the oxygen cost of maintaining body tissues was assumed to remain constant during exercise at a level represented by the basal metabolism To this requirement, the oxygen costs of breathing and pumping blood at increasing grades of work were added For example, actual measurements show that when the total oxygen uptake is 2.0 liters per minute, ventilation may be about 50 liters per minute and cardiac output about 20 liters per minute Therefore in plotting the broken curves in both quadrants the oxygen costs of breathing at 50 liters per minute and pumping blood at 20 liters per minute are summed Similarly, when total oxygen uptake is 3.5 liters per minute, the oxygen costs of breathing at 88 liters per minute and pumping blood at 25 liters per minute are summed It must be emphasized that the relative amounts of ventilation and cardiac output at a given grade of work vary in different people The values chosen in constructing Fig 9.1 are for purposes of illustration only They do not represent fixed relationships applying to all normal people When disease of the pulmonary or circulatory systems is present, the ratio of ventilation to cardiac output may be very different indeed

The following simplifying assumptions have been made in constructing Fig 9.1

1 $CO_2 - O_2$ exchange ratio (R) = 1, hence $V_{CO_2} = V_{O_2}$

2 Alveolar ventilation (V_A) = 0.862 V_E hence the dead space-tidal volume ratio (V_D/V_T) = 0.138

3 Alveolar P_{CO_2} ($P_{A_{CO_2}}$) = arterial P_{CO_2} ($P_{a_{CO_2}}$) = $\dfrac{V_{CO_2}\ (STPD) \times 862}{V_A\ (BTPS)}$

$$= \frac{V_{CO_2}\ (STPD) \times 862}{V_E\ (BTPS) \times .862} = \frac{V_{CO_2} \times 1000}{V_E}$$

4 Oxygen capacity of the blood = .20 ml oxygen per ml blood

5 Arterial oxygen saturation (Sa) = 95 percent or 0.95

6 $Ca - \bar{C}v = \dfrac{V_{O_2}}{Q}$ $Sa - \bar{S}v = \dfrac{V_{O_2}}{Q \times \text{oxygen capacity}}$, $\bar{S}v = 0.95 - \dfrac{V_{O_2}}{.20Q}$ where

Ca, $\bar{C}v$, Sa and $\bar{S}v$ represent arterial and mixed venous oxygen content and saturation respectively

Assumption (1) is justified because R approaches unity during exercise The low ratio of dead space to tidal volume assumed in (2) constitutes a reasonable approximation for a normal person during exercise The exact value chosen makes possible a cancellation of the factor 862 in (3) All P_{CO_2} isopleths would be more horizontal if the dead space to tidal volume ration were bigger The virtual identity of alveolar and arterial P_{CO_2} and the relationship between P_{CO_2}, V_{CO_2} and V_A are beyond question (1) Assumptions (4) and (5) represent average values for the blood of normal people who are exercising while breathing air at sea level Because of the flatness of the oxyhemoglobin dissociation curve at 95 percent saturation, the arterial oxygen saturation is not significantly affected by individual differences in ventilation Assumption (6) follows inescapably from the Fick equation and assumptions (4) and (5) All $\bar{S}_v$ isopleths would be more

ood flow were abnormally

is a compromise based on the published data of Cournand, Richards, Bader, Bader, and Fishman (10), McKerrow and Otis (21), and Campbell, Westlake, and Cherniack (7) The fact that different methods were used by each group of workers increases one s confidence in the general order of magnitude of the results The findings of McKerrow and Otis, and of Campbell, Westlake, and Cherniack in the higher ranges of ventilation suggest that the oxygen cost figures of Cournand, *et al*, may be a little too high However, the experimental subjects in both the former studies were tall lean men who had exceptionally high breathing capacities We have accordingly adjusted the cost of breathing curve to be as representative as possible of an average-sized man These considerations serve to emphasize that the oxygen cost of breathing varies with body size and also between different people of the same size Furthermore the maximum breathing capacity is known to increase during strenuous exercise (32,33) and it is not unlikely that there is an associated decrease in the oxygen cost of ventilating at high rates This might make the oxygen cost curve somewhat less steep under actual conditions of strenuous exercise

Wide variations between different people undoubtedly exist in the oxygen cost of pumping blood The curve shown on the right side of Fig 9 1 is based on very fragmentary evidence and is scarcely more than a guess, arrived at as follows At an oxygen uptake of 2 liters per minute, the cardiac output is approximately 20 liters per minute and the ventilation about 50 liters per minute in a normal person The areas of the pressure volume diagrams of the two ventricles, multiplied by the pulse rate, give a figure for the work done against pres

and an efficiency of cardiac action (based on work against pressure) of about 23 percent (5), one infers that blood is pumped about 3 times as efficiently as air Accordingly one would expect the oxygen cost of pumping blood to be about 12/3 or 4 times the oxygen cost of breathing at the specified rates Since at 50

liters per minute the oxygen cost of breathing is about 50 ml per minute, the oxygen *cost of pumping* blood *is estimated* to be about 200 ml per minute at a cardiac output of 20 liters per minute (as indicated on the right side of Fig 9 1) The rest of the curve for the oxygen cost of pumping blood is drawn free hand on the basis of this one orientation point The upper limit of 25 liters per minute is a reasonable value for a normal healthy man who is not a highly trained ath lete (6)

A graph such as this can be constructed only when a number *of simplify* ing assumptions are made Because of this its usefulness is chiefly in provid ing a starting point for a discussion of certain interrelationships The oxygen cost curves, in particular, must be used only as a means of visualizing the general trend of these phenomena and of understanding some of the ways in which the ability to exercise may be limited by the oxygen transport system The absolute values shown are not sufficiently reliable to be taken as average normal values

The relationship between ventilation and oxygen comsumption can be visualized in the *left* hand quadrant As long as P_{CO_2} remains constant, it is apparent that ventilation must increase in direct proportion to oxygen uptake P_{CO_2} does remain remarkably constant during steady state exercise and, by direct measurement, ventilation ordinarily increases in direct pro portion to oxygen uptake When extenuating circumstances exist, such as hypox
may r
of Pc
or emphysema, the reverse may occur

The *relationship between* cardiac output and oxygen consumption is *such* that if a proportional increase in each occurred, the saturation of the mixed venous blood would remain constant In fact, the saturation of the mixed *venous blood decreases during* exercise because blood flow fails to increase in proportion to oxygen uptake Cardiac output at any given oxygen con sumption must be adequate to keep the mixed venous blood saturation *above some minimum tolerable value*

The manner in which limiting factors come into play can be seen by considering increasing grades of work starting from no work at all Under basal conditions oxygen uptake *is only about* 250 *ml* per *minute, and* ven tilation *of only about 6 liters per minute is adequate to maintain a* P_{CO_2} of 40 mm Hg With a cardiac output of 5 liters per minute the saturation of the mixed venous blood is approximately 70 percent *This is the condition* of minimal stress on the ventilatory and circulatory systems

Most normal people can accomplish an oxygen consumption of 2 liters per minute without undue stress on the oxygen *transport system* At this level of work the ventilation rises to about 50 liters per minute, the P_{CO_2} remains at 40 mm Hg, and the cardiac output reaches about 20 liters per minute From the isopleths in the right hand quadrant it can be seen that

the mixed venous blood has a saturation of about 45 percent. Neither ventilation nor circulation has reached its upper limit.

An oxygen uptake of 3.5 liters per minute is reached only during very hard work. Most normal men, not in training, would have difficulty in maintaining this grade of work long enough to reach a steady state. The necessary ventilation for a P_{CO_2} of 40 mm. Hg is about 88 liters per minute. Not infrequently ventilation increases disproportionately during exhausting exercise, with lowering of P_{CO_2}. With a value of 25 liters per minute for cardiac output, the mixed venous blood saturation would be about 25 percent.

The highest values for oxygen consumption which to our knowledge have ever been recorded are for the cross-country skier, S. Jernberg (7). His oxygen uptake was 5.88 liters per minute and ventilation 146 liters per minute. When these two values are plotted in the left hand quadrant of Fig. 9.1 they meet at a P_{CO_2} value of 40 mm. Hg. The oxygen cost of breathing based on the curve in Fig. 9.1, would have been very high at a ventilation rate of 146 liters per minute, the slope of the oxygen cost curve being steeper than that of the isopleth for $P_{CO_2} = 40$. For reasons which will be discussed below, this would have been an untenable situation. Jernberg's maximum breathing capacity must have been higher and his oxygen cost of breathing at a given level of ventilation lower than that indicated by the cross hatched area. His curve may well have corresponded more closely to

blood would have been zero (unless the oxygen capacity of the blood was higher than 20 volumes percent). It is not unlikely that his cardiac output reached 35 liters per minute—a value which would have given him a mixed venous blood saturation of about 10 percent. In any case it is certain that his cardiac output exceeded the 25 liters per minute which we have assumed to be maximal for a normal man. Jernberg's pulse rate was 179 beats per minute which at a cardiac output of 35 liters per minute gives a stroke volume of just under 200 ml. per beat.

FACTORS LIMITING THE SUPPLY OF OXYGEN TO EXERCISING MUSCLES

The oxygen transport system appears to be like a well designed machine in that none of the parts normally has a functional limit which is much above or below the others. However, the stress on different parts of the system varies with different types of exercise and with different partial pressures of oxygen in the inspired air and there are variations between different normal people in the function of the different parts of the system. In disease states these differences may be greatly accentuated. For these reasons any discus

sion of the factors limiting the supply of oxygen to the exercising muscles must be qualified There is nevertheless evidence for the rather surprising statement that neither the heart nor the lungs is the limiting factor in the healthy well trained person

Let us first attempt to show from relationships in Fig 9 1 why the lungs appear to be exonerated The amount of oxygen supplied to the muscles may be taken as the difference between the total oxygen uptake and the oxygen cost of tissue maintenance and oxygen transport, represented by the curved broken lines near the bottom of each quadrant The largest amount of oxygen which the circulatory system could conceivably transport (without changing the basic assumptions on which Fig 9 1 was constructed) is identified by the intersection of a vertical line representing 25 liters per minute of cardiac output and the oblique line representing a mixed venous blood oxygen saturation of zero These lines intersect at a point representing an oxygen uptake of 4 8 liters per minute A horizontal line through this point intersects the isopleth for $P_{CO_2} = 40$ at a point representing a ventilation rate of 120 liters per minute If, at 120 liters per minute, the broken curve representing the oxygen cost of tissue maintenance and oxygen transport had a slope equal to or more vertical than, that of the isopleth for $P_{CO_2} = 40$, the supply of oxygen to the muscles would be limited by the rapidly rising cost of tissue maintenance and oxygen transport, i e, further increase in ventilation would not be associated with further increase in the supply of oxygen to the muscles However as drawn in Fig 9 1, the broken curve in the left hand quadrant is less vertical than the isopleth for $P_{CO_2} = 40$ at a ventilation rate of 120 liters per minute, and further increase in ventilation would therefore be associated with further increase in the supply of oxygen to the muscles The lungs would not have reached their effective functional limit even though the cardiac output had reached its limit

As a consequence of hypoxia, acidosis or other stimuli, ventilation during strenuous exercise often increases enough to reduce arterial P_{CO_2} below 40 mm Hg If under the hypothetical conditions being considered, P_{CO_2} dropped to 30 in association with a V_{O_2} of 4 8 liters per minute, a ventilation rate of 160 liters per minute would be required (Fig 9 1 or Equation 3) At this high value of ventilation the slope of the broken curve (oxygen cost of tissue maintenance and oxygen transport) would presumably be steeper than that of the isopleth for $P_{CO_2} = 30$ Accordingly the point of diminishing returns would have been reached with respect to the amount of oxygen available to the muscles, and the oxygen cost of breathing, which at this point would dominate the total cost of tissue maintenance and oxygen transport, could reasonably be considered the limiting factor

Direct measurements of ventilation during strenuous exercise have not, in our experience, yielded values for ventilation higher than 120 liters per minute At this point the broken curve in Fig 9 1 is considerably less steep than the isopleth for $P_{CO_2} = 40$ and somewhat less steep than the isopleth for

$Pco_2 = 30$ Thus, unless we have underestimated the cost of oxygen transport or the amount of ventilation associated with maximal exertion, the supply of oxygen to the muscles is not ordinarily limited by ventilatory function

It would appear from the above discussion that circulatory, rather than pulmonary, function limits the supply of oxygen to exercising muscles, but this should not be construed as meaning that cardiac function is the limiting factor Åstrand presents some cogent reasoning which leads him to believe that 'the capacity of the heart muscle to increase the cardiac output is greater than the ability of the skeletal muscle to receive it at least in exercise where only parts of the muscular mass are working e g in running (7) This concept is based on evidence that oxygen intake is lower during maximal work with the arms than it is during work with the legs, and lower during maximal work with the legs alone than during work with the legs and arms combined Exercising muscles are powerful pumps helping to return venous blood to the heart and it appears that an important factor in cardiac output is the number of pumps in action The ability of the muscles to receive blood may be virtually synonymous with their ability to return blood to the heart In any case, it seems not unlikely that peripheral vascular mechanisms, rather than the heart itself ordinarily limit blood flow during exercise

The oxygen cost of breathing may limit the exercise tolerance of patients in whom the work of breathing is greatly increased (oxygen cost curve much steeper than normal) Direct measurement of Pco_2 during exercise in patients with airway obstruction indicates that these patients adapt to the increased ventilatory stress by breathing less in relation to total carbon dioxide output, with resultant increase in Pco_2 It is apparent from Fig 9 1 that more oxygen is thereby made available to the muscles (The distance from the broken oxygen cost curve to the isopleth representing a Pco_2 of 50 is greater than the distance to the isopleth representing a Pco_2 of 40) The price, in physiological terms, is respiratory acidosis and an associated reduction in alveolar and arterial Po_2 If, as is often the case in disease states, the ratio of dead space to tidal volume should increase along with the increase in the work of breathing, all the isopleths on the left side of the figure would assume a more horizontal slope, the oxygen supplied to the muscles at any given level of ventilation would be reduced, and the maximum supply of oxygen would be reached at a lower level of ventilation

On the right side of Fig 9 1 the possible ways of limiting the supply of oxygen to the muscles can be seen to include elevation of the oxygen cost curve, lowering of the mixed venous blood isopleths, and limitation of cardiac output Theoretically the broken line representing the sum of the oxygen costs of tissue maintenance and oxygen transport might, in disease states, have a slope equal to or greater than that of the isopleth representing the minimum tolerable value for mixed venous blood saturation The mixed venous blood isopleths would assume a more horizontal position if for any reason the arterial oxygen saturation should be less than the 95 percent, or

the oxygen capacity of the blood less than the 20 volumes percent assumed in constructing Fig 9 1 Finally, the cardiac output might be limited either by failure of venous return or, in disease states, by inability of the heart to increase its output

The extent to which the heart and lungs can substitute for one another when the function of either is impaired can be visualized by constructing graphs comparable to Fig 9 1 in which any desired changes in the oxygen cost curves, in the ratios of ventilation to circulation, and in the slopes of the isopleths are made The high cardiac output of the emphysematous patient and the high ventilation of the cardiac patient probably increase the amount of oxygen available for physical exercise although it cannot be assumed that these adjustments necessarily achieve the best possible compromise Even among normal people there are wide variations in the ratio of ventilation to cardiac output during exercise It is not unlikely that physical training may alter this ratio

The subject of limiting factors, as deduced from Fig 9 1, can be summarized as follows in considering the possibility that the oxygen cost of breathing or the oxygen cost of pumping blood may be limiting the supply of oxygen to the muscles one must consider the slope of the curve formed

the point of diminishing returns for ventilation and the rapidly increasing

the slope of the curve of the two together in relation to the slopes of the appropriate isopleths for P_{CO_2} and Sv

Control of Breathing During Exercise

Gray in his study of pulmonary ventilation and its regulation, develops the multiple factor theory and gives equations defining the partial effects

produced by muscular contractions and acting through thermoreceptors is suggested as a factor of possible importance, but Gray has insufficient evidence to establish the point

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influences the ventilation indirectly via its effect on these two variables' (8) While there is no doubt that an increase in body temperature is associated with an increase in ventilation, whether at rest or during exercise, it seems unlikely that this effect, coupled with arterial Pco_2, is adequate to account for all the increase in ventilation during exercise (See addendum, p 175)

The ventilatory response in man during the first 15 seconds of exercise, under conditions which precluded any significant effect from either arterial Pco_2 or body temperature, was recently reported by Dejours, *et al* (12) Their findings extend the fundamental demonstration of Harrison, Calhoun, and Harrison in the dog that nervous stimuli brought about by active or passive movement of muscles cause an immediate increase in ventilation (16)

A reduction in ventilation occurs on moderate or strenuous exercise if 50–100 percent oxygen is added to the inspired gas This oft repeated finding has led to the theory that arterial hypoxemia occurs in severe exercise and causes a further rise in ventilation when other respiratory stimuli are maximally active (11) In support of this theory reference is made to direct measurements on the blood of Riley, whose arterial oxygen tension dropped from 94 mm Hg at rest to 73 during strenuous treadmill exercise (24) Riley appears to be unusual in this respect since reduction in arterial oxygen tension is not the expected response in normal people

In addition to mechanisms for controlling breathing during moderate physical exercise, there are probably reflexes which prevent excessive changes in intrathoracic pressure under extreme conditions Campbell discusses this point in his book on the respiratory muscles (6), and the idea is consistent with the finding of Marshall, Stone, and Christie that the negativity of intrathoracic pressure during maximum exertion reaches a peak value which is approximately the same in healthy people and in patients with obstructive disease (22)

There is recent evidence that ventilatory responses may be depressed by elevation of the hematocrit (14) or stimulated by noradrenaline (15) Specific chemoreceptors in the muscles which respond to local metabolic change by stimulating the respiratory centers in the brain have not been demonstrated conclusively, nor have chemoreceptors bathed by mixed venous blood from the pulmonary artery

Mechanics of Breathing During Exercise

Campbell presents electromyographic evidence that increased ventilation is ordinarily achieved primarily by increased activity of the inspiratory muscles This leads to increased distension of the lungs and greater elastic recoil during expiration During quiet breathing and at rates up to about 50 liters per minute, the inspiratory activity of the diaphragm and intercostals dominates the picture "During expiration there is some persistence of the con

traction of the inspiratory muscles particularly early in expiration *No mus cles of expiration are constantly active* Between 50 and 100 l/min the sternomastoids and the extensors of the vertebral column come into ac tion towards the end of inspiration The antero lateral abdominal and inter [illegible]

Dyspnea

The feeling of shortness of breath is difficult to define in physiological terms because of its subjective nature Dyspnea appears to be related more to mechanical than to chemical factors Cournand and Richards, studying patients with cardiac or pulmonary disease found it to be related both to reduction in ventilatory capacity and to increase in respiratory *stimulus and* ventilatory work (29 30) Marshall, Stone, and Christie introduced the concept of peak negativity of intrapulmonary pressure (22), which leads to the suggestion that reflexes related to pressure gradients across the pulmo nary and vascular structures within the thorax may contribute to the sensa tion of dyspnea It has been noted that the oxygen cost of breathing at very high rates may be so high that a further increment in ventilation reduces, rather than increases the amount of oxygen available to the muscles (31) The frustration of the control mechanisms under this unusual circumstance may have as its conscious expression the feeling of dyspnea Finally, there seems little doubt that the anguish of extreme fatigue may be difficult to distinguish from, or may indeed be part of the picture of, true dyspnea Here the patient with circulatory failure gives a clue for the inadequacy of blood flow in relation to metabolism resembles that of the exhausted athlete The work involved in taking a breath may seem overwhelming and may be called quite truthfully, labored breathing We conclude that dyspnea is a complicated symptom whose precise definition eludes us

Pulmonary Circulation

A number of workers have measured pulmonary artery pressure during physical exercise and found that it increases only a few mm Hg above the mean resting value of about 15 mm Hg until the flow reaches approximately three times the resting minute volume (16) At a still higher flow rates the pulmonary artery pressure increases much more sharply (17) While there are disagreements as to the exact quantitative relationship between flow and pressure, this pattern is generally accepted It implies that pulmonary vas cular resistance decreases progressively until the resting flow rate is approxi mately tripled and that resistance thereafter remains relatively constant This in turn implies that the vascular system approaches the limit of its dis tensibility when the cardiac output triples

Certain features of the behavior of the small pulmonary arteries can be inferred from the relationship between pressure and flow. Pressure would be expected to remain relatively constant at increasing flow rates if, as pressure began to increase, previously closed vessels opened, thereby increasing the total cross section of the vascular bed and minimizing the increase in pressure. Complete closure of small arteries except when transmural pressure exceeds a certain critical value would be consistent with Burton's concept of critical closing pressure (18). Presumably the vessels most likely to be closed would be those at the top of the lung (in the upright posture) because here the contribution of gravity to the transmural pressure gradient is minimal.

The behavior of the pulmonary capillaries can be studied from a number of different physiological approaches. Capillary pressure can be estimated by wedging a catheter into a small artery, and pressure in capillaries above and below this level can be inferred on the basis of hydrostatic considerations. Pulmonary capillary pressure at the level of the right auricle is normally about 11 mm Hg. The volume of blood in the pulmonary capillaries, as estimated by Roughton from studies with carbon monoxide, is approximately 60 ml at rest, increasing to about 95 ml during exercise (30). Roughton also estimates that the time required for red blood cells to traverse the pulmonary capillary changes from 0.75 seconds at rest to 0.34 seconds during exercise. The size of the capillary bed participating in gas exchange can be related to the pulmonary diffusing capacity. Findings with different diffusing capacity methods all suggest that the active capillary bed increases with exercise (see below).

Although experimental evidence related specifically to the pulmonary venous system is sparse, it can be assumed with reasonable confidence on basic hemodynamic principles that the mean circulatory filling pressure of the pulmonary vascular system increases with exercise (20). In the greater circulation, and presumably in the lesser, the mean circulatory filling pressure is dominated by conditions existing in the veins. An increased pressure contributes to increased venous return to the left side of the heart and hence to the increased cardiac output accompanying exercise. In association with increased venous filling pressure there is probably an increased volume of blood in the veins during exercise.

DISTRIBUTION OF BLOOD AND GAS THROUGHOUT THE LUNGS

Since for a normal person breathing air at sea level there is virtually no alveolocapillary diffusing gradient remaining at the end of the pulmonary capillaries, the entire difference in oxygen tension between the mixed expired gas and the arterial blood can be attributed to the manner in which blood and gas are distributed in the lungs and airways. A major part of this

discrepancy in oxygen tension arises out of the admixture of dead space gas to alveolar gas The anatomic dead space, which is bounded for the most part by compliant structures, increases with lung volume (21), and to the extent that the peak of inspiration reaches a higher lung volume during exercise, the anatomic dead space increases When the arterial P_{CO_2} is substituted for alveolar P_{CO_2} in the calculation of dead space by the Bohr equation, a different dead space results which is larger than the anatomic dead space because it includes contributions resulting from uneven distribution of blood and gas throughout the alveoli (22) This dead space likewise shows an increase during exercise, although the ratio of dead space to tidal volume stays the same or decreases The so-called venous admixture" refers to blood which bypasses the alveoli or passes through nonventilated or poorly ventilated regions (22) This value increases in absolute amount during exercise but the ratio of venous admixture to total blood flow usually stays the same or decreases The alveolar oxygen tension ordinarily increases a little during exercise, largely because of the increase in the CO_2-O_2 ex

ventilated areas are unpredictable Emphysematous patients, for example, may show either an increase or a decrease in the arterial oxygen tension with exercise, indicating either improvement or further impairment in the distribution of blood and gas throughout the lungs

ALVEOLAR CAPILLARY DIFFUSION

There is general agreement that the diffusing capacity of the lung increases during physical exercise There our agreement ends, because the amount of the increase and the shape of the graph of diffusing capacity vs oxygen uptake differ when investigated by different methods (25,26) It is enough for purposes of the present discussion to state that the diffusing capacity during exercise at sea level increases enough to permit a close approximation of the oxygen tension in the alveolar gas to that in the blood leaving the alveolar capillaries The ability to perform physical exercise is thus not normally limited by inadequate pulmonary diffusing capacity As in the case of ventilation and blood flow, however, the maximum capacity of the average normal person with respect to diffusion would be inadequate for the superior athlete

Fig 9 2, prepared by Dr Richard H Shepard, illustrates some of these relationships very dramatically (32) It can be seen that at any given value for diffusing capacity the oxygen saturation of the blood leaving the alveolar capillaries is very little affected by increasing oxygen consumption until a critical point is reached When the oxygen consumption increases beyond this point, the oxygen saturation of the blood drops precipitously Direct measurements of the oxygen saturation of the arterial blood show that the

normal person exercising at sea level cannot increase his oxygen consumption enough to cause unsaturation of his arterial blood From inspection of Fig 9 2, it seems likely that the skier Jernberg, whose oxygen consumption approached 6 liters per minute, had a pulmonary diffusing capacity in the range of 100

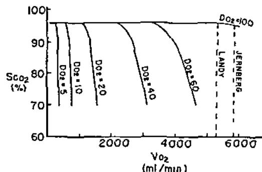


FIG 9 2 *Relationships between the oxygen saturation of the blood leaving the alveolar capillaries (Sc O), total oxygen consumption ($\dot{V}O_2$), and diffusing capacity (DO) When, for any given value of DO_2, VO exceeds a certain critical value $Sc'O_2$ drops precipitously (Prepared from calculations by Dr R H Shepard)*

No discussion of diffusion is complete without reference to the amazing achievements of mountain climbers It is now well recognized that the diffusion gradient at the end of the alveolar capillary is much larger at low levels of ambient oxygen tension than at sea level and that at low ambient oxygen tension the diffusing capacity has a much more important effect upon the arterial oxygen saturation (24) Calculations indicate that a large diffusing capacity is needed to prevent extreme hypoxemia when the oxygen uptake is increased at high altitude To the extent that hypoxia resulting from inadequate diffusing capacity limits the ability to perform physical exercise at high altitude, it may be said that exercise tolerance is "diffusion limited"

ADDENDUM

There is now considerable evidence that ventilation is stimulated during exercise by a powerful chemoreflex involving nerve endings bathed by mixed venous blood Preliminary studies in this laboratory (Johns Hopkins Hospital, Baltimore) suggest that the receptor area is in close relation to the first portion of the pulmonary artery

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LUCIEN BROUHA AND
EDWARD P. RADFORD, JR

The Cardiovascular System in Muscular Activity

SUMMARY

During muscular activity oxygen must be supplied by the blood to the working muscles in proportion to their requirements, and carbon dioxide and heat produced by increased metabolism must be dissipated In order to do so the cardiac output increases and blood flow is redistributed so that an adequate amount reaches the active muscles and the skin With submaximal exertion, oxygen consumption and cardiac output can be maintained at a steady state for long periods, but during maximum effort oxygen consumption reaches an upper limit and the muscles draw heavily upon anaerobic processes, under these conditions exercise cannot be maintained for long Maximum oxygen consumption may depend in most individuals on limitations of total cardiac output or blood flow to the exercising muscles The return of the cardiovascular system to the pre exercise level is determined by the exercise performed and by the heat load produced by muscular activity and the environment Age, sex, and fitness influence quantitatively the cardiovascular reactions to exercise Because of the importance of cardiovascular adaptations during muscular activity, the circulatory responses of the individual play an important part in determining his athletic ability

INTRODUCTION

One of the most important physiological changes produced by muscular activity is an increase in blood circulation to the exercising muscles It is an essential phenomenon because if circulation to the muscles does not increase, muscular contractions cannot be sustained for any significant length of time and consequently exercise must stop The increased circulation is needed for several reasons to supply more materials, chiefly oxygen, to the muscles as

sources of energy for the contractions, to remove waste products, such as carbon dioxide and lactic acid, which otherwise would rapidly accumulate and impair muscle function, and to permit a greater dissipation of heat produced by muscular activity Except for small and localized movements involving only a few muscles, the total output of the heart must increase during exercise this presentation will be concerned with cardiovascular responses to moderate or heavy exercise involving most of the major muscle groups

Adaptations of the cardiovascular system to muscular activity have been extensively studied and the action of many factors has been investigated in animals, frequently by means of radical experimental procedures In intact organisms, particularly in man, research is limited by the techniques that can be used without impairing the subject s health or his performance This fact reduces substantially the number of observations made directly on men during and after exercise

Recent papers and reviews discuss the complex factors governing cardiovascular function Since it would be impossible to summarize all of them within the scope of this chapter, the interested reader is referred to the bibliography This presentation is limited to a description of the cardiovascular reactions of healthy man to muscular activity without systematically trying to explain the mechanisms involved It should be realized that because of lack of information the overall picture remains incomplete

For the sake of clarity the metabolic requirements and the circulatory adjustments necessary to meet them during exercise are first considered A second part presents briefly the cardiovascular responses to exercise as influenced by age sex and individual fitness The effects on the circulation of environment acclimatization and training are discussed in other chapters

CIRCULATORY REQUIREMENTS DURING EXERCISE

Aerobic Versus Anaerobic Muscular Contractions

The changes that take place in the contracting muscles and their requirements for performing work determine the chain of events occurring in the

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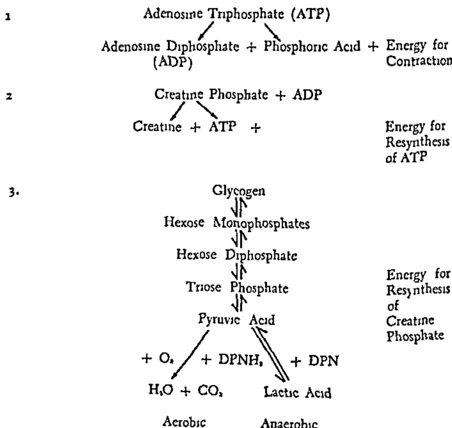
Normally the energy of muscular contraction comes from the oxidation of glycogen[1] to carbon dioxide and water, oxygen is not indispensable for contraction itself but it is necessary for the recovery phase

According to currently accepted theories the chemical changes accom

[1] Other sources of energy (e g fat) may be oxidized also but for the sake of simplicity only glycogen will be considered here

panying the contraction of muscle proteins can be presented in simplified form as follows

During contraction the mechanical shortening of the muscle fibers is related to the breakdown of adenosine triphosphate into adenosine diphosphate and phosphoric acid with the liberation of energy and heat This reaction is followed by the breakdown of creatine phosphate into creatine and phosphoric acid, accompanied by the resynthesis of adenosine triphosphate



During relaxation glycogen breaks down to water and carbon dioxide with the consumption of oxygen, or to lactic acid in the anaerobic process (see diagram) In either case the chain of reactions liberates energy for the resynthesis of creatine phosphate

When oxygen is available in an adequate amount, muscular contractions are carried out by aerobic processes and little or no lactic acid is formed

Pyruvic acid is completely oxidized to carbon dioxide and water, this final result being reached through a series of intermediate reactions controlled by specific enzymes When oxygen delivery is inadequate to the demands, anaerobic processes can substitute in part for aerobic and energy can still be released Under anaerobic conditions lactic acid is formed in the muscles and continues to be produced for a short time after the end of contraction, *its production is independent of oxygen utilization When most of the work* is done anaerobically, lactic acid may be produced at a rate up to 3 to 4 grams per second (21)

When exercise stops, lactate continues to escape from the muscles for a

Recent studies have shown (22) that when blood lactate is corrected for changes in pyruvate levels (which modifies lactate by a mass action effect) "excess" blood lactate after exercise correlates closely with the oxygen debt

The maximum rate of exercise that can be performed depends not only on the efficiency with which the lungs and circulatory system provide the working muscles with oxygen (maximum oxygen consumption), but also on the ability of the individual to utilize anaerobic metabolism (e g, maximum production of lactic acid) The degree to which anaerobic processes are brought into action depends on the level of exercise Muscular work may be classified in terms of oxygen consumption as follows

Light	= 0 5 to 1 0 liter O_2 per minute
Moderate	= 1 0 to 2 0 liters O_2 per minute
Heavy	*= greater than 2 0 liters O_2 per minute*

In normal individuals undertaking light exercise, oxygen supply is adequate and keeps pace with the requirements of the muscles Work is done almost completely aerobically with a uniform oxygen consumption and the small amount of pyruvic acid formed in the muscles is kept constant by a balance between the rates of formation and removal Lactic acid does not accumulate in the muscles and little lactate appears in the blood A 'steady state' of oxygen consumption is reached and maintained throughout the period of muscular activity

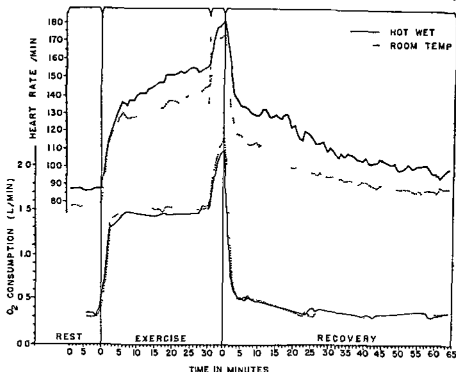
During moderate exercise, as long as oxygen supply is adequate, a balance between the breakdown processes and the recovery processes in the muscles is reached at a higher level of oxygen consumption and of pyruvic acid concentration When the oxygen supply becomes inadequate, lactic acid is formed and overflows into the blood stream Even then, unless the oxygen supply becomes grossly inadequate, a metabolic steady state can still be maintained, the more severe the exercise, the higher the level of the steady state of oxygen consumption and of blood lactate concentration

In maximum exercise it is no longer possible to reach a metabolic steady

state, anaerobic processes become predominant and lactic acid accumulates until the performance stops The "oxygen debt" incurred by anaerobic metabolism is paid during the recovery period following the performance Considering that for most individuals the total amount of lactic acid that is tolerable is about 90 grams, maximal anaerobic exertion can last only for about thirty seconds (23) Lactic acid concentration in the blood, however, does not appear to be the limiting factor to maximum performance or a primary cause of fatigue As noted by Dill *et al* (16), when half of the oxygen debt is paid after six to eight minutes of recovery, the capacity for anaerobic work is almost completely restored, at that time the blood lactic acid may be at its maximum value As mentioned above (22), the corrected "excess" blood lactate does correlate with oxygen debt, which may be considered an index of fatigue

In the preceding paragraphs we have used two concepts that are not always clearly defined, namely, "steady state" and "oxygen debt" Unless specifically qualified, the expression "steady state" can be misleading A *steady state* of physiological adjustment is reached when all the factors regulating a given function are in balance and maintain the function at a constant level When steady state refers to oxygen consumption, it means that oxygen intake is equal to the oxygen utilized, and body stores of oxygen remain constant On the other hand, a steady state of glycogen stores is never achieved in heavy exercise because the muscles continuously draw upon these reserves Under these conditions a steady state of blood glucose may be reached but at the expense of the glycogen storage which is constantly reduced Originally the term "steady state" referred to a uniform rate of oxygen consumption (21) It is often taken for granted that when a uniform rate of oxygen consumption is maintained, a steady state also exists for other physiological functions, such as pulmonary ventilation, heart rate, body temperature, or blood pressure This is definitely not the case For example, oxygen consumption can be maintained in a steady state throughout the exercise period, but a continuous increase of heart rate and cardiac output may be observed because of a progressive circulatory requirement for heat dissipation Fig 10 1 gives an example of this phenomenon Similarly during a steady state of oxygen consumption the thermoregulating mechanisms may not be able to maintain a thermal steady state and body temperature will rise It is therefore essential when using the expression "steady state" to indicate to what physiological function or functions it applies

The *oxygen debt* refers to the extent to which anaerobic processes were utilized to achieve the performance When exercise involving anaerobic processes in the muscles stops, the consumption of oxygen remains at an increased level during the recovery period The value of the debt is the amount of oxygen consumed above the resting level between the end of exercise and the return to the resting level of oxygen consumption The fact that the oxygen debt has been paid and that oxygen consumption has returned to its



work (540 kg m/min) followed by a 4 minute period of maximum work (900 kg m/min) Although a steady state of oxygen consumption was reached at the lower load in both environments the heart rate continued to increase particularly with the hot wet environment Oxygen consumption recovered rapidly after work, to the resting level but even after an hour the heart rate did not recover, presumably because of an increased skin blood flow

resting level does not necessarily mean that the recovery processes are complete In many instances heart rate, for example, can remain above resting levels long after oxygen consumption has returned to its resting rate (Fig 10 1)

Steps in Oxygen Utilization

When heavy demands are made to supply oxygen to the muscles and to eliminate carbon dioxide, the cardiopulmonary system must operate adequately through a series of physiological steps

The *first step* in the process involves the drawing in of environmental air to be mixed with the lung gases This step involves a mechanical deformation of the lungs produced by the respiratory muscles during inspiration and

expiration The most important requirements of this mechanical process are first, the inspired gas should be distributed uniformly to the terminal units

by the respiratory muscles

The *second step* in gas transport involves diffusion of oxygen from the gas phase into the blood and diffusion of carbon dioxide from the blood into the gas phase Many complex physicochemical properties of blood and tissues are important in transfer of gas to the pulmonary blood, just as they are when oxygen is exchanged for carbon dioxide in the muscles, and a detailed discussion will not be undertaken here Important factors determining the capability of the individual in this process are the area of the lung surface, the barrier to diffusion offered by the lung tissues, the rate at which hemoglobin is carried by the blood past the lung surface, and the completeness with which the blood is exposed to the lung gases [2]

The *third step* is related to the velocity of blood flow produced by the heart, acting as a pump and to the mechanisms, generally reflex, which regulate the distribution of blood to the various organs The capacity of the blood to transport oxygen is determined almost entirely by the total concentration of hemoglobin in the red cells Thus the only two ways by which more oxygen can be carried to any tissue is by increasing the flow of blood or by a greater extraction of oxygen from the blood Both of these mechanisms are important during exercise It should be realized that the demands made by the muscles for increased blood flow are not the sole determinants of circulatory requirements during exercise, since the blood supply to vital organs such as the brain must be maintained regardless of the circulatory demands elsewhere Moreover, as heat production increases, the circulation to the skin must increase to provide for cooling

The *fourth step* in the transport of gases involves diffusion from the blood into the muscles where oxygen is utilized for energy production, and diffusion of carbon dioxide from the muscles into the blood to return it to the lungs for excretion The important factors in this aspect of gas transfer are largely unknown but probably include the capillary circulation per unit of muscle mass, the effects of muscle contraction and relaxation on the blood flow, and the diffusion gradients required to produce the necessary flow of gas into or out of the muscle

The *final step* in oxygen utilization is determined by the rate of transfer of oxygen from the free molecular state to its incorporation in the oxidized molecules The affinity for oxygen of the enzymes responsible for these transfers appears to be so high (*12*) that their rate of uptake is unaffected unless the concentration of oxygen falls to very low levels To describe the

[2] The influence of changes in the pulmonary diffusion capacity' on exercise tolerance is discussed in the chapter on respiration

process occurring at low oxygen concentrations by the term 'anaerobic metabolism' is perhaps unfortunate, for in fact lactic acid production occurs alongside oxidative breakdown of pyruvate when oxidation potential in the tissues falls The relative amount of lactic acid produced depends on the effect of the oxidation potential on the DPN oxidation reduction equilibrium

The above presentation has outlined the oxygen and carbon dioxide exchanges in healthy man At any of the above steps the oxidative capacity of the system may become limited by disease It is only when all these physiological processes function effectively that an individual can exercise at high levels of energy expenditure for any length of time Much research has been done in an attempt to determine which of the processes cited above limits the normal individual in the amount of work he can do without shifting from aerobic to anaerobic metabolism No clear-cut answer to this question has as yet been found, suggesting that a delicate balance of several limiting factors in all stages of oxidative metabolism exists at peak levels of exercise It is quite possible that one or another of these factors may be limiting depending on slight differences in the anatomical or physiological properties of the individual

In summary, the lungs must be able to oxygenate the arterial blood efficiently, oxygen must be supplied by the blood to the working muscles in proportion to their requirements, and the muscles must be able to utilize oxygen As long as the oxygen requirements are met, muscular activity is performed aerobically and can last for a long time When the oxygen supply is no longer adequate, anaerobic processes limit the performance The crucial role of the cardiovascular system in carrying oxygen to the working muscles is evident

Cardiovascular Adaptation to Exercise

Some of the circulatory changes required by exercise have been briefly outlined in the preceding section we shall now proceed to consider them in greater detail

Cardiac Output The most important phenomenon in cardiovascular function during muscular activity is the increase in cardiac output, i e, the total volume of blood expelled by the heart per minute This greater output is achieved by an increase both in the number of heart beats per minute and in the volume of blood pumped with each beat (stroke volume) For exercise of short duration (up to five minutes) the relation between cardiac output and exercise level, as measured by oxygen consumption per minute, is shown schematically in Fig 10 2 For a tenfold increase in oxygen consumption, the cardiac output increases about five times This increase is produced by direct nervous and humoral effects on the heart itself and by a greater return of blood to the heart from the peripheral circulation The relative importance of these two factors on the heart and the mechanisms

which influence them are not fully understood at present, but it is probable that the nervous and humoral regulations are of major importance, acting both on the heart rate and on the strength of contraction of the heart muscle

Heart Rate and Stroke Volume The cardiac output equals the heart rate (beats/min) times the stroke volume (liters/beat) It also equals the oxygen consumption (cc /min) divided by the mean arteriovenous (A V) oxygen difference (cc /liter)

$$\text{Cardiac output} = \text{Heart rate} \times \text{Stroke volume} = \frac{\text{Total oxygen consumption}}{\text{Mean A V oxygen difference}}$$

Consequently the total oxygen consumption equals the product of the heart rate times stroke volume times mean A V oxygen difference A presentation of the changes in these variables during exercise is given in Fig 10 2

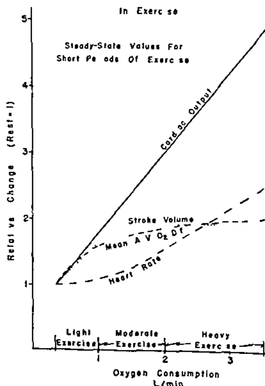


FIG 10 2 *Relative changes (rest = 1) in cardiovascular responses as a function of intensity of work (oxygen consumption) With light exercise changes in stroke volume of the heart account for most of the increase in cardiac output, with heavy exercise the stroke volume becomes relatively constant and the cardiac output is proportional to heart rate These relative changes apply only after cardiovascular responses reach steady values*

At an oxygen consumption greater than 1 liter per minute the A V oxygen difference and the stroke volume are reasonably constant for any given subject, although considerable differences exist between individuals in their absolute levels This constancy accounts for the direct relation found between heart rate and cardiac output or oxygen consumption during exercise at moderate ambient temperature

Modifications of heart rate and stroke volume are about equal in producing the increased cardiac output during exercise (Fig 10 2) The stroke volume at rest varies considerably in the same subject, and it also depends on the posture of the individual, being about 30 per cent smaller in the standing than in the supine position

For a standing male subject the stroke volume is about 60 to 80 cc per beat Because of the smaller size of the heart in women, their stroke volume is lower and their heart rate about 20 percent higher than for men at equal oxygen consumption The stroke volume doubles or triples during moderate or severe exercise, and this rise in stroke volume is not associated with a consistent increase in the size of the heart during diastole Roentgenographic evidence suggests that the increased stroke volume is due to a greater emptying of the heart with each beat rather than to a greater diastolic filling, but it should be recognized that this point is still controversial and the evidence is largely indirect (2) The increased stroke volume implies a greater vigor of contraction of the heart muscle, mediated in part at least by nervous and hormonal actions on the heart

At rest the heart rate is apt to be quite variable depending not only upon posture but on the emotional state of the individual Usually in athletic contests the heart rate rises before exercise has begun and this faster heart rate may be associated with a proportional increase in cardiac output It depends on the athlete s anticipation of the coming exercise and suggests that cardiovascular responses during exercise are partly mediated by the central nervous system The precise degree to which changes in heart rate arise from nervous impulses in the cerebral cortex or in the medulla oblongata is uncertain The central role of the medullary centers in regulating all forms of motor activity suggests that they act as a coordinator of vasomotor, respiratory, and somatic muscular activity Afferent reflex stimuli from the auricles and great vessels and from the muscles themselves may also be important in producing the changes in heart rate, as well as the liberation of epinephrine and norepinephrine from the adrenal medulla

As soon as muscular activity begins, the heart rate quickly rises As the *heart rate increases during exercise, the fraction of each cardiac cycle devoted* to systole increases slightly and the fraction devoted to diastole decreases The short diastolic interval available for filling is apparently not of great physiological significance, however since no clear-cut evidence has been obtained that stroke volume falls off at very fast pulse rates produced by heavy exercise (3) Heart rates greater than 200 beats per minute have been recorded in subjects driving themselves to very high levels of performance, but under usual conditions during hard exercise the heart rate increases up to about two and one-half times the resting value

When exercise stops, the heart rate for a few seconds is very close to the maximum attained at the end of exercise Then recovery takes place and the behavior of the heart rate is determined by the preceding exercise and the environmental conditions (Fig 10 1)

Changes in Blood Pressure, the Venous Return of Blood to the Heart The circulatory changes during exercise are brought about with only a slight rise in the mean blood pressure measured in the central arteries of the systemic circulation For this reason redistribution of blood flow from the

viscera to the exercising muscles and if necessary to the skin involves vaso constriction in the former and vasodilatation in the latter These reactions are presumably coordinated via the vasomotor center in the medulla oblongata

During exercise systolic and pulse pressures increase with the work load while diastolic pressure changes are insignificant (Fig 10 3) When a steady

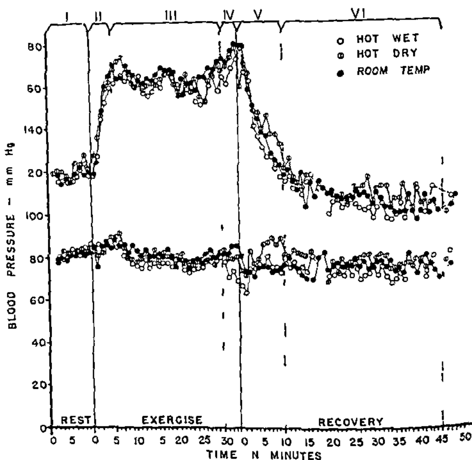


Fig 10 3 Changes in systolic (upper curves) and diastolic (lower curves) blood pressure measured from auscultatory sounds obtained with a microphone over the brachial artery Same experiments as shown in Fig 10 1 except that a third environment (hot dry 99°F and 25% RH) is also included

state of oxygen consumption is reached blood pressure remains at a constant

half as much as the systolic pressure and in most types of exercise it is

reasonable to say that it does not increase by more than 10 or 20 mm of mercury

Pressure changes in other parts of the greater circulation such as the capillaries and veins vary depending on location These changes have not been measured in most cases and can only be inferred from local hemodynamic changes known to be produced by exercise For example, in relatively inert capillary beds, as in the brain little effect of exercise should be expected In capillary beds which show vasodilatation such as in the skin, both capillary and venous pressures rise In the active muscles the pressure changes in capillaries and veins are complicated by the squeezing effect of muscular contraction on these vessels As the muscles contract, the resistance rises in the capillaries and the blood flow presumably falls At the same time the deep veins adjacent to the muscles are emptied, and because of the venous valves, the blood is forced toward the heart In this way the contracting muscles act as an auxiliary circulatory pump (muscle pump) assisting the return of blood to the heart The importance of this pumping action of the muscles depends on the type of exercise in running it undoubtedly serves an essential circulatory role by preventing pooling of blood in the leg veins

Another auxiliary pumping mechanism assists the return of blood to the heart and modifies the pressure in the central veins As pulmonary ventilation increases during exercise, the mean intrathoracic pressure becomes more negative and, as the abdominal muscles become active the intra abdominal pressure increases during expiration These pressures are probably transmitted almost completely to the thin walled veins and thus a pressure gradient promoting venous flow into the thorax is established The importance of this 'respiratory pump on the circulation also depends on the type of exercise For example, during running it undoubtedly assists the return of blood to the heart, but in rowing if the glottis is closed during the stroke, the intrathoracic pressure rises with the abdominal pressure and venous return of blood from the extremities is inhibited rather than promoted

The effects of exercise on the pressures in the pulmonary circulation are less complex than for the greater circulation Normally pulmonary vascular pressures and resistance are low and changes are difficult to evaluate When pulmonary pressures are measured relative to the mean intrathoracic pressure, the mean pulmonary arterial pressure rises moderately during heavy work and the greatly increased blood flow is accounted for by a fall in resistance in the pulmonary circulation The output of the right and left ventricles is maintained in close balance, but the extent to which the blood volume in the lungs changes during exercise remains uncertain because of a lack of reliable methods for assessing it

The return of arterial blood pressure to the resting values during the recovery depends on the severity of exercise After moderate or submaximal efforts of comparatively short duration, the systolic pressure drops rapidly to

the pre-exercise level and remains constant thereafter. Since the diastolic pressure does not change significantly, the pulse pressure follows the same pattern After exhausting exercise the systolic pressure decreases rapidly to below the resting level, the diastolic may follow the same trend or remain unchanged and consequently the pulse pressure falls, sometimes to values as low as 15 to 20 mm mercury Thirty to sixty minutes after exercise the blood pressure usually returns to its resting level (11)

Distribution of Blood Flow In addition to the need for increasing the flow of blood to active muscles, blood distribution must also be adequate to meet the metabolic requirements of the other tissues Distribution of the total blood flow to supply various parts of the body is shown schematically in Fig 10.4 These results are approximate and primarily based on data ob-

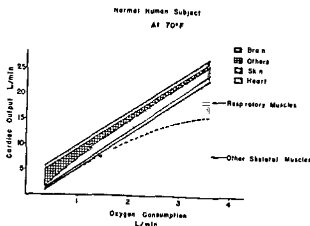


FIG 10.4 *Distribution of total cardiac output to various areas as a function of oxygen consumption, values reached after short periods of exercise at normal temperature The figure is based on data of Bishop (5) and others and represents an approximation only, particularly with respect to skin blood flow Visceral blood flow, represented as "others," is markedly decreased with moderate to heavy exercise, and practically all of the increase in total blood flow goes to the muscles The proportion of flow going to respiratory muscles has been derived indirectly and probably varies considerably from individual to individual*

tained by Bishop[3] (5) for exercise at moderate environmental temperature for short periods Fig 10.4 shows that the blood flow to the brain remains unchanged, reflecting the necessity for the brain to maintain its oxidative metabolism at all times The group referred to as "others" includes chiefly

[3] We are greatly indebted to Dr J M Bishop for making his thesis available to us

the abdominal viscera (kidneys, liver, intestine, and spleen) Under resting conditions most of the cardiac output goes to these organs, but with increasing severity of exercise the proportion of blood reaching the abdominal viscera decreases to a relatively small fraction of the total In spite of a large cardiac output the coronary blood flow itself only increases two to threefold within this range of exercise This remarkably small change in coronary flow reflects the efficiency of the heart as a pump and will be discussed in more detail later Although in Fig 10.4 skin blood flow is shown to increase moderately, this cutaneous portion should be considered only as a rough estimate, for it is markedly dependent upon individual variations in the efficiency of heat dissipation, duration of exercise, and environmental temperature Regardless of the values assumed for the various fractions of the total blood flow, it is apparent from Fig 10.4 that at high levels of exercise the blood flow to the muscles constitutes the major part of the cardiac output

The amount of blood actually available to the exercising muscles is limited not only by the ability of the heart to increase the cardiac output and by the fraction required to flow through the skin to permit cooling but also by the amount of blood going to the muscles involved in respiration During heavy exercise this includes not only the diaphragm, the muscle mainly used during quiet breathing, but also practically all of the trunk muscles which at high levels of pulmonary ventilation are necessary to assist respiration The precise relation between respiratory muscle blood flow and total oxygen consumption is unknown and the proportion of total cardiac output going to the respiratory muscles is still highly uncertain The dashed line drawn in Fig 10.4 is a rough estimate based on data for the work of breathing obtained by different authors (24,26) The important point is to note that in contrast to the heart, the oxygen and blood flow required by the respiratory pump increase very sharply at high levels of exercise Whether at oxygen consumptions above 3 liters per minute the blood flow needed by the respiratory muscles in any way limits the blood flow available for the rest of the skeletal muscles is uncertain It probably depends on the type of exercise as well as on individual variations in the mechanics of breathing

Arteriovenous Oxygen Difference, Oxygen Extraction from the Blood If an increase in the rate of flow of blood were the only mechanism available for supplying greater amounts of oxygen to the muscles, it is apparent that the portion of the cardiac output reaching the muscles would have to be directly proportional to the total oxygen consumption As cited above, however, another way in which the body can obtain more oxygen is by extracting

the venous blood approximately doubles due to a fall in venous oxygen saturation In normal subjects, Donald and co-workers (17) found that un

der their experimental conditions the A V oxygen difference, which at rest was about 5 to 6 cc per 100 ml of blood, did not increase above 13 cc per 100 ml of blood Venous blood coming from the exercising muscles showed an A V oxygen difference up to 16 to 17 cc per 100 ml depending on the severity of exercise (18) The degree of extraction of oxygen by the exercising muscles may well be a significant factor determining an athlete's performance particularly when maximum cardiac output is reached

Blood Volume Hemoglobin During exercise, the cardiovascular system can provide an adequate circulation of blood to the muscles and to the skin only if the blood volume is sufficient to meet these requirements It is obvious that if a significant portion of the blood were to be pooled in one part of the circulation or another, the venous pressure might fall below the level necessary to return a sufficient volume of blood to the heart An adequate blood volume is particularly essential when the blood vessels of the skin are dilated for heat dissipation In this case a large amount of blood may be deflected into the cutaneous vessels and the venous return may become inadequate to maintain a large stroke volume at an elevated heart rate

Astrand (3) has found a high correlation between total blood hemoglobin (normally closely correlated to blood volume) and the maximum oxygen intake for both males and females This correlation between body hemoglobin and maximum oxygen intake may depend upon the fact that both indices reflect the general size of the individual On the other hand, an increase in total red cells and hemoglobin is considered an important adaptation for individuals to acclimatize to exercise at high altitude

CARDIOVASCULAR ADAPTATION AND HEAT DISSIPATION

In addition to supplying oxygen to the working muscles, adjustment of the cardiovascular system is important to remove heat produced by muscular activity Exercise increases the production of heat by the muscles, and this heat must be dissipated in order to maintain the body temperature within safe limits A simple calculation illustrates the heat accumulation which is possible, assuming metabolism is entirely aerobic Taking the caloric equivalent as 5 calories per liter of oxygen consumed, at an oxygen consumption of 2 liters per minute above the basal level, aerobic heat production would be 10 calories per minute above basal Ten calories would raise 50 kilograms of body water 0 2°C, therefore at this work level the body temperature would rise about 0 2°C or 0.4°F per minute if heat dissipation remained at the basal rate

The circulatory mechanisms of heat dissipation obviously become more important the heavier the exercise and the warmer the surroundings Under these conditions cutaneous vasodilatation occurs and the blood flow to the skin increases, hence the cardiac output must increase The effect of a high environmental temperature on the distribution of blood flow is illustrated in Fig 10 5 No experimental data are available on the extent of

skin vasodilatation which would permit precise drawing of the curves, and they should be considered as rough approximations They show that in a warm environment the skin blood flow, which is already considerable at rest, *increases markedly as oxygen consumption* and heat production become greater during exercise Thus the maximum cardiac output, taken here to be about 25 liters per minute, is reached at a relatively low work level as compared with that shown in Fig 10 4 Fig 10 5 properly applies only to the steady state during short periods of exercise, for more prolonged exercise the increase in skin blood flow may be even more important

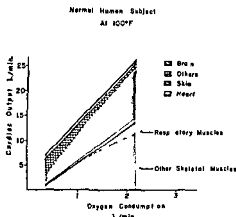


Fig 10 5 *Distribution of blood flow for exercise in a hot environment based on same data as Fig 10 4 with an esti ... hese ... de ... dura tion of exercise, and individual differ ences in vasomotor responses to body ... be reached*

The rise in skin blood flow is necessary not only to provide heat loss by conduction from the blood, but also to provide for metabolic and water requirements of the sweat glands As sweating becomes profuse, significant amounts of body water may be lost, the resulting dehydration places an additional strain on the cardiovascular system because of a decrease in circulating blood volume and a rise in viscosity of the blood In normally hydrated subjects these effects of dehydration are seen only with prolonged exercise in a hot environment

Although vasodilatation of the skin vessels invariably occurs when heavy exercise is maintained for more than a few minutes, as exercise begins a transient constriction of skin vessels may occur (15) The change to vasodilatation and sweating may be related to the phenomenon of "second wind," because various experimental procedures modifying thermal balance have been found to influence its onset (23) One may speculate that as a result of the initial increase in heat production and initial decrease in heat dissipation due to vasoconstriction, a rapid rise of temperature occurs in the nervous centers of respiratory and cardiovascular control leading to the cardiorespiratory symptoms preceding "second wind"

During exercise in hot environments, particularly when the humidity is high, sweating and heat conduction may not be sufficient to dissipate the heat load produced by the exercise Under these conditions body tempera-

ture rises and the cardiovascular responses such as heart rate and cardiac output continue to increase, even though the exercise level and oxygen consumption remain constant (Fig 10 1) When body temperature exceeds 102°F, the subject usually will end the exercise voluntarily The ability to reach a high level of oxygen intake and to maintain satisfactory thermal equilibrium are the two most important circulatory factors necessary to achieve an outstanding athletic performance The interrelation of factors limiting exercise in hot environments is discussed in another chapter

Effects of Exercise on the Heart

The heart muscle functions like other striated muscles and the energy for its contraction derives from similar chemical reactions Nevertheless some essential differences exist First of all is the fact that the activity of the heart never stops Consequently even in a resting individual, the oxygen extraction by the heart is similar to that observed for skeletal muscles during moderate work Secondly the heart possesses the important characteristic that its oxygen requirement does not necessarily increase in proportion to its external work it can therefore function at high levels of physical activity *with a relatively small increase in oxygen consumption and in coronary flow* Thirdly the nature of the chemical reactions taking place during contraction show some differences from those occurring in voluntary muscles The heart can use glucose for its metabolism but in too small a quantity to supply all its energy requirements Unlike skeletal muscle it uses lactic and pyruvic acids obtained directly from the blood The amount of glucose and lactate utilized vary reciprocally if there is no lactate, more glucose is consumed and vice versa Y Bogue and his co workers (6) have shown that glucose and lactic acid consumption are both increased when the work of the heart becomes greater and that the glycogen of the heart muscle is formed from blood glucose but not from lactate During heavy exercise the heart muscle utilizes its own glycogen, but it is not known whether the heart under normal conditions draws on its glycogen and replaces it from blood glucose or whether it burns glucose and lactate directly, keeping its glycogen reserve for emergencies When oxygen supply to the cardiac muscle is inadequate, the heart contractions become partly anaerobic, lactic acid is formed and glycogen is utilized

The oxygen supply to the heart muscle depends on the coronary blood flow The most rapid entry of blood into the coronary arteries takes place during diastole During isometric ventricular contraction the inflow is abruptly reduced It increases again as soon as the ventricular ejection phase begins and follows the variations of aortic pressure until the end of systole A sudden increase of inflow occurs again with ventricular relaxation diminishing progressively with decreasing aortic pressure until the next systole occurs

As the heart rate goes up during exercise, the diastolic phase is shortened

and consequently there is less time per beat to deliver oxygen to the heart muscle Since even at rest the A V oxygen difference in the coronary blood is already great, a significant increase in oxygen availability during exercise can be provided only by a larger coronary blood flow If the oxygen consumption of the heart were proportional to its external work during exercise, it would be unable to increase the cardiac output without a proportionate increase in coronary flow, which at a high heart rate might be a severe limitation

Sarnoff and his co-workers (28) have used an isolated heart preparation in dogs in order to study the hemodynamic determinants of myocardial oxygen consumption When the work of the left ventricle was increased by elevating the aortic pressure and holding cardiac output and heart rate constant, oxygen consumption of the myocardium increased with aortic pressure When heart rate was increased but cardiac output, mean aortic pressure, and work remained constant, myocardial oxygen consumption again increased In contrast, when the work of the heart was increased by elevating cardiac

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cardiac output or external work done by the heart The fact that cardiac output can increase with a comparatively small rise in myocardial oxygen consumption has also been shown by others (1) and has been found in intact animals (20)

In the intact individual the heart is regulated by the central nervous system which increases or diminishes cardiac activity according to the integrated needs of the whole body Most of this regulation is achieved by the balance between the braking action of the vagus nerves and the stimulating effect of the sympathetic nerves An increase in vagal tone slows the heart rate and reduces the coronary flow An increase in sympathetic tone conversely quickens the heart rate, relaxes the coronary vessels, and increases the coronary blood flow In addition sympathetic stimulation markedly increases the energy of contraction and thus increases the stroke volume During exercise the combination of a decreased vagal tone and an increased sympathetic activity causes the heart to beat more strongly and the heart rate to quicken, the moderately increased oxygen requirements of the heart are met by a simultaneous increase in coronary blood flow

Regulation of the heart is also influenced by hormonal factors, chiefly by epinephrine and norepinephrine produced by the adrenal medulla Before and during exercise these hormones are released by stimulation of the sympathetic nervous system and their action is similar to that of the sympathetic fibers innervating the heart Although there are quantitative differences in their effects, epinephrine and norepinephrine both increase the coronary flow (30) and act directly upon the myocardium to reinforce the strength of contraction Neurohumoral regulation of coronary flow, of heart rate, and strength of contraction of the heart determines in large part the

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responses of the heart to exercise is far from understood in the intact individual the most striking facts of the heart s performance are its ability to increase its external work with a comparatively small increase in oxygen consumption, and to utilize lactic acid directly as a source of energy, which is a great asset in severe muscular exercise when lactate is abundant in the circulating blood The result is that the heart is able to meet the requirements placed upon it by exercise without making excessive circulatory demands itself Because of the high level of efficiency of the heart, it is reasonable to consider that in normal subjects the metabolism of the heart itself is not a limiting factor during maximum exercise

FACTORS INFLUENCING THE CARDIOVASCULAR REACTIONS TO EXERCISE

The responses of the cardiovascular system to muscular work follow qualitatively the above described patterns, but they differ quantitatively in healthy individuals, being influenced by factors such as the kind of exercise, and the subject s age, sex, and inherent fitness

Influence of the Kind of Exercise

Aerobic and anaerobic processes are utilized to various degrees in different sports, and therefore the demands upon the cardiovascular system vary For short, exhausting types of activity anaerobic contractions are used to a maximum, resulting in a large oxygen debt and a high concentration of lactic acid Sprinting is a typical example of this kind of exertion maximum effort of short duration, during which the cardiovascular system cannot meet the oxygen requirements of the muscles The athlete draws on oxygen reserves and anaerobic processes during the sprint and pays the oxygen debt after the race is over

For exhausting types of activity of longer duration, such as middle-distance running or swimming, aerobic metabolism is maximal, and submaximal

the performance If a maximum oxygen debt is reached early in the race, the athlete must slow down or stop completely

For efforts of long duration pushed to exhaustion, such as long distance running, skiing, swimming, or cycling, it is essential to maintain a steady

state of oxygen supply during the greatest part of the performance Only at the start and during the final sprint are anaerobic processes involved *The higher the level of oxygen steady state that can be maintained, the more work that can be produced aerobically and the better the performance*

For efforts of long duration that are not pushed to exhaustion, such as long marches, mountain climbing, or agricultural and industrial work, it is most economical to be able to maintain a steady state of oxygen consumption as low as possible throughout the performance The whole effort should be accomplished with a minimum of anaerobic metabolism, and no appreciable oxygen debt The one who can keep the pace with the lowest oxygen requirement is the most efficient, and he usually can sustain the work for the *longest time*

For alternating efforts of various intensity, such as in tennis, boxing and football, where periods of intense activity are followed by periods of comparatively low activity or rest, the problem of rate of repayment of the anaerobic debt is of considerable importance In this case both aerobic and anaerobic processes are used according to the varying grades of effort, which can be maximum for relatively short bursts An athlete who, after producing a maximum effort, can return rapidly toward the resting state has an advantage, since he can pay the debt contracted anaerobically during peak efforts, and will be ready to produce another peak effort sooner than one requiring longer to recover The level at which aerobic metabolism is partially or totally replaced by anaerobic processes depends on the degree of activity for which the individual can maintain a steady state of oxygen supply the more exercise that can be performed aerobically the less 'borrowing' from the anaerobic phase and the less time needed to pay that oxygen debt during reduced activity or rest Consequently, an athlete who is able to *reach a high steady state of oxygen consumption and to recover quickly* from repeated efforts involving anaerobic contractions will achieve a high level of physiological efficiency

The question now arises how can we evaluate the specific effects on the cardiovascular system of various kinds and intensities of exercise? Most of the factors involved in cardiovascular adaptation to exercise have been studied using laboratory techniques, including measurements of stroke volume, *cardiac output, peripheral resistance, etc* As previously mentioned, in man, research is limited by the methods that can be used without impairing the subject's health or his performance This consideration restricts the kind of measurements that can be made directly during muscular activity Fortunately, because of its close relation to cardiac output and oxygen consumption (Fig 10 2), heart rate can be utilized to evaluate the stress imposed by muscular activity upon the heart and the circulation with a minimum *amount of interference with the subject's freedom* of motion and performance ability As a single factor it quite accurately depicts the cardiovascular adjustment of the individual to muscular activity The following presenta

tion is based upon heart rate variations during exercise and during recovery as an index of the cardiovascular responses

During light exercise the first increase in heart rate may be exaggerated and subsequently the rate diminishes to a lower level which is maintained as exercise progresses (Fig 10 6, curve 1) For a heavier work load the heart

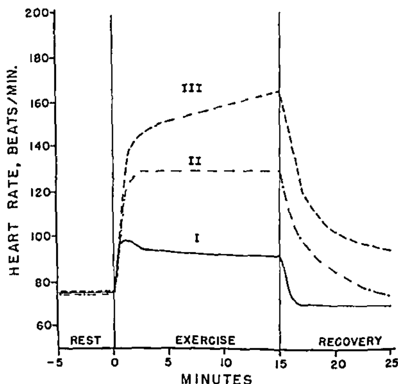


Fig 10 6 *Heart rate changes as an index of cardiovascular responses during exercise and recovery for three work levels of increasing severity I light to moderate exercise, II moderate exercise, III heavy exercise*

rate reaches a rather constant level which persists throughout the exercise (Fig 10 6, curve 2) These constant levels are described as a "steady state" of heart rate When the intensity of exercise is further increased, no steady state can be attained and there is a continued progressive increase in heart rate until exercise stops (Fig 10 6, curve 3) These three typical curves are observed [illegible]

period [illegible]

exercise [illegible] Under [illegible] tions the cardiovascular system is stressed to its maximum and the subject, reaching exhaustion, must stop

For constant work of sufficient intensity the duration of exercise also in

fluences the cardiovascular responses If the subject has been able to maintain a steady state for a given time and if the work is prolonged, a secondary and progressive increase in heart rate takes place until exercise stops

When the work load varies during exercise, the pattern of the cardiovascular *reactions follows each change closely as indicated by the fact* that an increase in load produces an increase in heart rate and vice versa The relative abruptness of the change depends on the degree of difference in work loads For a small load increase the heart rate will rise smoothly to establish a new, more elevated plateau, for a marked load increase the change is rapid, the adaptation to the heavier load starts immediately, and is achieved in a short time The reverse is true for decreasing work loads

In sustained static contractions, such as weight lifting, the heart rate accelerates slightly, remains unchanged or even slows down during the effort However, when the effort is terminated, the heart rate remains elevated for a time which is determined by the magnitude of the effort and the muscles that were involved

When exercise is repeated several times with periods of rest intervening the same reactions are found For moderate exercise the cardiovascular reactions reach the same level during each period of activity For harder exercise the heart rate increases further with each successive period of work and no steady state can be maintained throughout the total performance

Recovery of the Circulation After Exercise After light work the cardiovascular functions soon return to the pre exercise resting level The heavier the load, the higher will be the maximum heart rate and the longer it will take to return to the resting level (Fig 10 6) The duration of exercise also influences the recovery processes If the load is light duration has little influence unless it extends over several hours For heavy work that can nevertheless be maintained in a steady state, the longer the duration of exercise, the longer the recovery to the resting level (e g, marathon runners, mountain climbers) On the other hand, for comparatively short efforts pushed to exhaustion or nearly so, the duration of the performance does not influence appreciably the recovery processes No matter how long it takes to reach exhaustion, the return to the resting heart rate always follows the same pattern and takes about the same time (Fig 10 7)

When exercise is not continuous the cardiovascular recovery reactions during the rest periods are determined by the total previous work performed For light or moderate exercise the recovery is complete in a short time even after several periods of activity This pattern represents a steady rate of recovery ' For harder work the recovery rates remain at a progressively higher level as the number of exercise periods increases By proper adjustment of the sequence, exercise rest periods, it is possible to maintain over a long time the same heart rate pattern during each work and recovery cycle If a steady level of recovery is to be achieved, the rest periods must become longer as the exercise is repeated As soon as the rest time becomes too short,

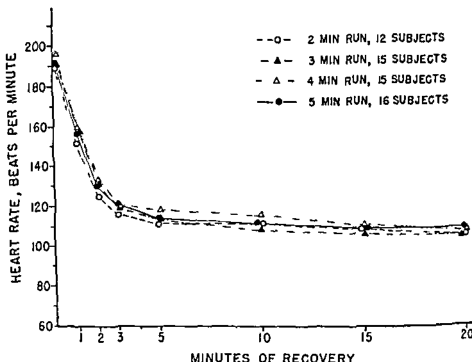


FIG 10 7 *Recovery of heart rate after exercise Four groups of male subjects run to exhaustion on a treadmill exercise voluntarily stopped by the subjects Those men in poorest physical condition could run only for two minutes while the most fit subjects ran for five minutes Despite the differences in work done, the peak pulse rate reached by each group was the same at exhaustion, and recovery of the heart rate showed the same change with time*

the heart rate increases during successive periods of both work and recovery A steady state can no longer be maintained and the subject comes closer and closer to his maximum working capacity and his exhaustion level (tennis players, successive rounds of boxing)

INFLUENCE OF INDIVIDUAL FACTORS

Age, sex, and fitness influence quantitatively the adaptation of the cardiovascular system to exercise

For example, in adolescents we have found a much higher correlation between the ability to perform hard exercise and the size of the individual than with his age (19), and similar results have been reported by Astrand (3) It seems that after about 25 to 30 years of age the maximum oxygen consumption diminishes progressively, this decrease is associated with decreases in cardiovascular and respiratory capacity Later in life, although maximum per

formances of youth are no longer attainable, the reactions to submaximal work are definitely related more to the fitness of the individual than to his age The well known marathon runner, DeMar, and the former tennis champion, Borotra, are striking examples of this fact Even after the age of 60, these two men had better work capacity than some men of 20

Effects of Sex Marked differences exist between the physiological capacity of men and women to perform hard exercise (3,25), especially with respect to cardiovascular adaptations For the stroke volume Christensen

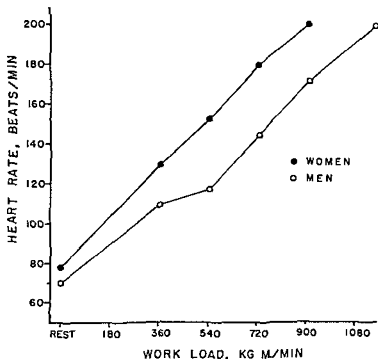


FIG 10 8 *Maximum heart rate reached by women and men for five minutes exercise on a bicycle ergometer as a function of external load The heart rate (and by inference, cardiac output) increases roughly in proportion to the external work done The higher heart rates of women at all work loads reflect their smaller stroke volume per beat* Highest values were obtained *for exhausting work (subjects forced to stop), at this point the heart rate was the same for both men and women, about 200 beats per minute*

(13) has reported maximum values of 209 ml for men and 161 ml for women, with maximum cardiac output 37 liters for the men and 25 liters for the women The average A V difference was 10 8 cc oxygen per 100 ml of blood for the women and 13 1 cc oxygen for the men Consequently, for a given oxygen intake the heart rate is higher in females than in males and for a given heart rate the men achieve a greater oxygen transport than the

TABLE 10.1 Means and Extremes of Values for Selected Physiologic Variables for 17 Women and 30 Men Performing Moderate and Strenuous Exercise

	MEANS		EXTREMES			
	Women	Men	Women		Men	
Walk (3.5 m.p.h. on 8.6 percent grade for 15 min.)						
Ventilation, cc./min./kg.*	610	552	467	831	421	748
O_2 consumed cc./min./kg.* (9–14 min.)	27.8	29.6	25.3	30.2	24.5	38.3
R.Q.—maximum	0.91	0.89	0.84	0.99	0.56	0.97
Blood lactate mg. percent	40	21	26	58	9	38
Blood sugar mg. percent	115	112	88	141	89	131
Pulse rate—1 min.	152	140	134	177	112	162
Pulse rate—3 min.	168	143	150	190	115	168
Pulse rate—maximum	179	151	156	200	120	172
Recovery pulse—1 min.	139	116	111	172	85	162
Recovery pulse—2½ min.	123	107	93	141	82	135
Recovery pulse—5 min.	112	91	82	143	75	124
Systolic pressure—1 min.	148	148	130	160	122	176
Diastolic pressure—1 min.	84	74	76	98	60	90
Run (7 m.p.h. on 8.6 percent grade until exhausted)						
Duration (sec.)	108	216	70	186	105	300
Ventilation cc./min./kg.* (maximum)	975	1112	716	1220	690	1400
O_2 consumed cc./min./kg.* (maximum)	40.9	51.3	29.6	47.5	30.5	60.5
R.Q.—maximum	1.06	1.14	0.72	1.30	0.81	1.45
Blood lactate mg. percent (maximum)	112	119	69	144	68	178
Blood sugar mg. percent (maximum)	156	144	113	235	114	194
Pulse rate—1 min.	188	177	170	202	157	192
Pulse rate—maximum	197	194	181	206	178	210
Recovery pulse—1 min.	163	158	145	180	128	180
Recovery pulse—2½ min.	132	124	111	151	102	148
Recovery pulse—5 min.	116	114	105	137	95	136
Systolic pressure—1 min.	163	181	140	190	140	212
Diastolic pressure—1 min.	88	77	78	108	48	96

SOURCE: Data from E. Metheny, L. Brouha, R. E. Johnson, and W. H. Forbes, "Some Physiologic Responses of Women and Men to Moderate and Strenuous Exercise: A Comparative Study," *Amer. J. Physiology*, 1942, 137, 320.

* Body weight.

women during submaximal and maximal work. The aerobic capacity is 25 to 30 percent lower in women.

Even for light work (360 kg.m./min.) performed on a bicycle ergometer, women show heart rates higher than those of the men although their re-

covery patterns are quite similar During heavier exercise (540 or 720 kg m / min), the heart rates of the women are markedly higher than those of the men and their recovery to the pre exercise level is slower (8) In both sexes the maximum increase in heart rate with increasing work follows a straight line, but exhaustion is reached at a lower work load for women than for men (Fig 10 8) Table 10 1 compares some physiological variables observed in men and women performing moderate and strenuous exercise on the treadmill The highest heart rates for both sexes have been observed by Christensen and Hogberg (14) after long distance ski racing They report that after a ski race of 5 km the average values were found to be 240 beats per minute for boys in the 14 to 16 year age group Boys in the 17 to 20-year group had an average of 237 after a 10 km race Girls between 15 and 17 reached an average of 250 after a 5 km ski race Four subjects in this group had rates above 270 After a ski race of 18 km, well trained young women had an average heart rate of 214, whereas well trained adult men seldom had maximum heart rates above 200 beats per minute These very high values can be explained by the fact that the skiing races were always finished at the maximum speed attainable by the competitors in a final sprint

Effects of Fitness of the Individual The fitness of the individual is prob

TABLE 10 2 Variations of Physiological Measurements on Young Men During and After Muscular Work

I Moderate Work (Walking for 15 min at 3 5 m p h on Treadmill, grade 8 6%)*

Measurement	Mean	Sigma	Range
Heart rate			
before start	85 8	12 8	50–115
at 2 min walk	140 3	11 5	94–168
at 10 min walk	145 0	16 0	98–175
at 15 min walk	149 0	15 1	112–180
1 min after walk	110 2	16 4	68–147
2 min after walk	105 1	15 7	65–144
5 min after walk	98 0	13 0	56–120
Systolic blood pressure			
before walk	123 0	9 4	102–144
1 min after walk	150 2	14 4	118–176
5 min after walk	124 6	9 8	102–154
Blood lactate during walk	20 3	6 6	9–37
Blood sugar during walk	112 4	13 0	80–143
O_2 consumption cc per kilo, during walk	28 7	2 7	22 5–37 7
Ventilation during walk (liters per minute)	38 8	4 4	24 7–49 3

* N = 75

TABLE 10 2 (*Continued*)

II Exhausting Work (Running up to 5 min at 7 m p h on Treadmill, grade 8 6%)[a]

Measurement	Mean	Sigma	Range
Heart rate before start	112 5	18 7	58–160
Duration of run	3′59″	1′12″	1′20′–5′
Heart rate			
at 1 min run	177 0	10 0	150–192
at 2 min run	187 0	9 8	162–205
at 5 min run	193 6	9 6	173–208
25 sec after run	181 2	9 7	150–198
1 min after run	155 8	14 9	92–183
3 min after run	118 8	13 2	80–146
10 min after run	109 9	11 8	75–145
25 min after run	105 8	12 0	68–131
Systolic blood pressure			
1 min after run	186 8	16 4	140–226
5 min after run	143 8	16 2	98–180
25 min after run	113 7	10 5	86–136
Blood lactate 5 min after run	118 6	29 5	31–203
Blood lactate 25 min after run	68 9	24 6	21–137
Blood sugar 5 min after run	142 4	21 1	83–194
Mx O_2 consumption during run and per kilo	50 7	6 0	30 9–62 0
Ventilation during run, liters per minute	78 8	13 6	34 8–108 2

SOURCE Data from Variability of Physiological Measurements in Normal Young Men at Rest and During Muscular Work by L Brouha and B M Savage Revue canadienne de Biologie, 4 136 1945

ably the most important factor determining the level of cardiovascular reactions to exercise Table 10 1 shows that among healthy subjects of either sex and of approximately the same age marked variations are found in the capacity to perform muscular work and to recover from it Table 10 2 presents data collected on healthy college students It emphasizes the individual variability of physiological level for various functions measured at rest, during and after moderate exercise, and during and after exhausting performance The capacity of these men to perform hard muscular work was evaluated by the following measurements duration of a run on a treadmill at 7 m p h and on 8 6 percent grade, blood pressure before and after work, pulmonary ventilation and oxygen consumption during the run, heart rate before, during, and after work, blood sugar and blood lactate before and after work Taking into account these various factors, it was possible to determine how efficiently an individual can perform exhausting work (10) Accordingly, the subjects were divided into four categories in regard to their performing ca

pacity poor, average, good, and excellent On the basis of that classification and due to the fact that physical fitness for hard muscular work depends to a great extent on adaptations of the circulation, it was found that for a standard amount of moderate or submaximal work a fit subject is able to maintain a slower heart rate during work and to recover more quickly after work than a less fit individual For maximum work the fit and the unfit may attain the same maximum heart rate, but the fit subject is able to perform more work before he reaches that level Such results demonstrate that physiological measurements during and after exercise are indispensable to establish *an adequate distribution of normal individuals according to a scale of* physiological capability The estimate of capacity to do muscular work should be based on the subject's actual ability to perform it and on the speed of recovery after exercise

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11

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ELSWORTH R BUSKIRK

Exercise and Body Fluids

SUMMARY

Exercise changes the dynamic body fluid equilibrium A single bout of work or athletic event may induce changes that are relatively transitory (hemoconcentration) or long lasting (red cell destruction with subsequent augmented erythropoiesis) In general, information describing both acute and chronic shifts in body fluids with exercise is meager Reliance must be placed on measurements that are in most cases rather indirect and frequently inaccurate

The various body fluid volumes in normal young adults at rest, together with some of the means of measurement, have been discussed so that exercise induced changes may be viewed in proper perspective

Complete bed rest is associated with a decrease in plasma and blood volume which is evident after three weeks Both volumes return toward pre-bed rest values if bed rest is discontinued or reconditioning is employed

Hemoconcentration and a diminution of plasma volume accompany the assumption of the upright position from the supine The changes are of sufficient magnitude to be considered in the interpretation of findings from exercise experiments Light and moderate work induce homoconcentration and plasma volume changes similar to those found with standing If standing or light exercise is continued, pre standing or pre-exercise values are reattained Walking, cycling, or running at high work levels produce hemoconcentration and loss of plasma water to the interstitial fluid over and above the postural change

Elevated total circulating hemoglobin and blood volume values have been found in physically trained individuals (carbon monoxide method) These findings have not been confirmed with other methods Since myoglobin as well as hemoglobin may bind carbon monoxide, the carbon monoxide

method may only provide a measure of the total hemo myoglobin pool in … assessing … secondar … ing hemoglobin if cardiac output is proven to be the important factor limiting the severity of physical work

Sustained training or habitual physical activity seem to involve no permanent body fluid shift as a primary effect, but prolonged strenuous training is usually accompanied by a decreased percentage of fat and an increased percentage of fat free mass Thus an increase in the percent of total body water particularly intracellular water accompanies an increase in the percent of fat free body weight due to exercise

Dehydration limits man s ability to perform physical work largely through impaired cardiovascular function Physical conditioning or training may provide sufficient cardiovascular reserve so that the deleterious effects of dehydration on work performance are minimized Hemorrhage of 500 cc may reduce work performance capacity for several days although the effects on work performance are quite variable

Only a partial foundation has been built for understanding the effects of exercise on body fluids What remains unknown presents a challenge and opportunity to many specialties in physiological amd medical research

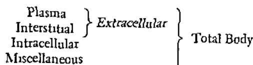
INTRODUCTION

This chapter is devoted almost exclusively to a discussion of exercise induced water exchange in the healthy adult body The effects of both short term and long term (single bout of exercise and habitual exercise) are considered Although fluid compartments have been defined and are discussed as such they should not be visualized as discrete entities Each compartment is variable in size, changeable in composition, and undergoes constant modification because of continuous shifts of water, electrolyte, and organic molecules Since the post World War II development and advancement of the techniques and application of flame photometric and radioactive tracer methods, *there has been increased interest in describing* the fluid volume and solute shifts that occur within the body Nevertheless this interest has not carried over to the detailed study of water and solute shifts induced by everyday events, such as exercise In this chapter current knowledge of the impact of exercise on the body fluid volumes is presented *together with discussion of some of the problems that remain unsolved*

Mention of electrolyte or other solute shifts, while intimately related to fluid shifts, is brief, the reader is referred to the excellent discussions of Gamble (33) and of Elkinton and Danowski (30) for a comprehensive treatment of these topics as well as a discussion of the effects of various experimental and pathological conditions on body fluid volumes

DESCRIPTION OF FLUID VOLUMES

The body may be considered divided into the following fluid volumes



Fluid volume is larger than water volume, because *fluid volume* is the sum of water volume plus any additional space taken up by substances dissolved or suspended in the water For precise measurement, appropriate corrections must be applied to obtain water from fluid volume or vice versa, however, in this discussion the terms are used interchangeably

Plasma volume is the volume of extracellular fluid contained within the blood vessels Plasma volume is usually measured by using a dye or label, such as T 1824 or I^{131} labeled plasma protein Each of these gives only approximate values for the plasma volume (38,76)

Although red-cell volume is not strictly a fluid volume, it has considerable import to a discussion of exercise physiology *Red cell volume* is frequently determined by measuring the plasma volume and hematocrit, applying a correction for trapped plasma, and then calculating the red-cell volume More direct methods are available and include the administration of a substance such as carbon monoxide which is preferentially affixed in the blood cell, or the injection of red cells labeled with a radioactive tracer (Cr^{51}, Fe^{55}, Fe^{59}, and P^{32}) (36,39)

Extracellular fluid is the volume of fluid outside the cells and includes plasma and interstitial fluid Extracellular fluid has been estimated by dilution of numerous substances including sodium, chloride, sucrose, mannitol, inulin, thiosulfate, and thiocyanate Although some of these substances yield similar volumes, the values measured are dependent on the type of material administered Thus the resulting measurement is usually referred to as "sucrose space," etc, rather than "extracellular space" A review of the various "extracellular" fluid volumes has been prepared by Lavietes, *et al* (57) *One other volume, ' transcellular fluid,* has been identified as part of the extracellular fluid *Transcellular fluid* is defined as that fluid residing within hollow organs Although this volume appropriately is part of extracellular fluid, it is not measured by most of the substances used to assess extracellular fluid and may be erroneously identified with intracellular water (98)

Interstitial fluid is calculated by subtracting the plasma volume from extracellular fluid and is the volume of fluid between the vascular system and the cells, it includes lymph

The total body water volume is the sum of the component water volumes

The total volume has been measured with isotopically labeled water urea antipyrine or an antipyrine derivative Although these tracers may not equilibrate with sequestered water (miscellaneous volume in the out line) such as that in bone and cartilage before all samples are drawn, only a slight error is introduced from this cause Some of the hydrogen in iso topically labeled water is also known to exchange with the hydrogen in or ganic compounds

Intracellular water is determined by subtracting extracellular fluid from total body water A more direct method for determining intracellular water has not been found although attempts have been made with K^{42} (64)

Numerical values for the various fluid volumes for a normal (nonexer cised or nonstressed) young male adult appear in Table 11 1 with references

TABLE 11 1 Average Values for and Methods of Measurement of Body Fluid Volumes in Normal Young Male Adults* (Units percent of total body wt)

Volume	Value	Method	Author	Reference	Year
Plasma (PV)	4 1	T 1824	Edelman *et al*	(28)	1952
	4 1		Hicks *et al*	(40)	1956
	4 5		Moore *et al*	(64)	1956
Red cell (RCV)	2 9	Cr^{51} or P^{32}	Hicks *et al*	(40)	1956
	3 0	Fe^{59}	Edelman *et al*	(28)	1952
	3 2	Cr^{51}	Sterling & Gray	(86)	1952
Total Blood	7 5	PV + RCV	Hicks *et al*	(40)	1956
Interstitial	22	ECW PV	Edelman *et al*	(28)	1952
Intracellular	36	TBW ECW	Edelman *et al*	(28)	1952
Extracellular (ECW)	15 7	Inulin	Schwartz *et al*	(80)	1952
	16 6	Na_2SO_4	Cardozo & Edelman	(15)	1952
	18 8	SO_4	Edelman *et al*	(28)	1952
	23 5	SCN	Edelman *et al*	(28)	1952
Total body water (TBW)	55	Desiccation	Forbes & Lewis	(32)	1956
	59	Antipyrine	Picon Reategui & Lozano	(73)	1957
	61	DHO	Edelman *et al*	(28)	1952

* Values for normal young adult males in the age range 20–30 years were not always available Values for older individuals are included (cf 32)

to the authors cited The errors involved in each fluid volume measurement

of confirmation by direct analysis

Seasonal variations in body fluid volumes may occur which unless con sidered might confuse interpretation of a change induced by training or

physical conditioning Monkeys (67) have a NaSCN space (approximating the extracellular space) of 250 cc /kg in summer and only 184 cc / kg in winter Doupe and others (24) reported that in 72 males observed for 1–2 years, plasma volume (T 1824), red blood cell mass, circulating hemoglobin, and total circulating plasma proteins all increased during the summer and decreased during the winter

During exercise several mechanisms probably act simultaneously to change body fluid volumes (see Fig 11 1) Some of these mechanisms are discussed in the section on Acute Exercise One important mechanism, however, deserves mention in this introductory section—the Starling equilibrium This equilibrium is illustrated in Fig 11 1 (30), along with other mechanisms which may be less important during exercise The relative distribution of water between the intravascular and interstitial compartments is determined by the ratio between intravascular hydrostatic plus interstitial osmotic (largely protein) pressures which tend to force fluid into the tissue spaces, and by *intravenous osmotic plus interstitial hydrostatic pressures which tend* to force fluid into the capillaries The normal course of events is for a relatively protein free filtrate of plasma to leave the arterial end of the capillary and a protein free filtrate of interstitial fluid to enter at the venous end Thus any factor affecting hydrostatic or osmotic pressures will influence volume distribution, and this factor may be obscured or forgotten by simply attributing the volume shift to exercise Detailed discussion of the Starling equilibrium may be found in most texts of physiology but it is particularly well treated in Elkinton and Danowski (30)

Other mechanisms not mentioned elsewhere in this chapter are also important, however, the contribution of each in relation to a single bout of exercise or to an extended exercise program is not clear in many instances It has been stated that receptors sensitive to changes in effective blood volume are located in or near the walls of the vascular system (9,12,72) Red cell volume, in general, responds slowly (over days) to a change in oxygen content in the tissues [1] When the red cell volume deviates from normal, blood volume is maintained by an appropriate change in plasma volume Known mechanisms of body fluid control do not explain the close regulation of extracellular fluid The existence of a 'volume receptor" (in addition to an osmoreceptor partially controlling thirst) has been postulated (9,72), which is sensitive to changes in extracellular fluid volume, or to some closely related function Such a volume receptor might influence sodium excretion, and therefore water excretion by control of renal tubular or sweat gland activity Other transport mechanisms for ions and water by cell membranes

National Institutes of Health personal communication)

have been postulated to explain effects not explainable by diffusion alone An "ıon pump" or "water pump," if such exists, makes a contribution of un known kind and amount to body fluid shifts under various conditions Hormonal control is manifested by changes in vasomotor activity (vasodilata

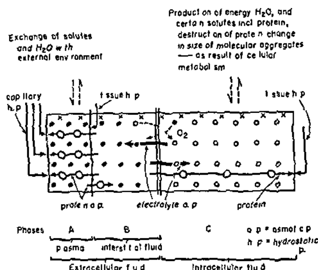


FIG 11 1 *Diagram of the four mechanisms of fluid transfer as integrated in the three phase system Plasma interstitial fluid intracellular fluid (Elkinton and Danowski, 30)*

"Hydrostatic pressures are indicated by the angulated arrows outside the phases of fluid, osmotic pressures by the horizontal arrows within Large open circles represent protein solutes restricted to the several phases Small open and solid circles represent ionic solutes such as electrolytes restricted to the intracellular and extracellular phases respectively by a process of active transfer requiring energy .

are freely diffusi-
xert no differential

"The distribution of fluid between the intravascular plasma and the extravascular interstitial fluid is determined by the relationship of the hydrostatic and oncotic or protein pressures according to the Starling hypothesis

" Fluid is distributed between the extracellular and intracellular phases mainly according to the osmotic pressures resulting from the active differential distribution of electrolytes

"The broken reaction arrows above the plasma and above the intracellular fluid indicate that, with respect to forces that effect movements of fluid, the system is open at both ends"

tion and vasoconstriction) and permeability, and changes in rates of fluid and electrolytes loss from the body Adrenaline and noradrenaline have been shown to modify vasomotor activity and influence nonthermal sweating, antidiuretic hormone alters the amount of water lost in urine, while aldosterone modifies urinary sodium and potassium excretion (99)

The alterations in kidney function during various types of exercise are discussed elsewhere in this book Suffice it to say that the kidney plays an important role in regulation of the composition and volume of the extracellular fluids The sweat glands also participate in regulation in that both volume and composition of sweat may be modified as a result of acclimatization to heat accomplished by work in the heat The mechanisms mentioned above may influence either kidney or sweat gland function or both

BED REST AND PLASMA VOLUME

Plasma volume has been shown to decrease during three weeks of bed rest both with (21) and without (88) immobilization In the immobilization study (21) four men were secured in plaster casts covering their legs and pelvic girdles and remained in bed for six to seven weeks The decrease in plasma volume (T 1824) during the first three weeks ranged from 120–320 cc and averaged 191 cc or 6 3 percent of the preimmobilization plasma volume (blood volume [T 1824 + hematocrit] decreased 275 cc or 5 4 percent) During the remaining three to four weeks of bed rest plasma volume returned toward preimmobilization values During the reconditioning following immobilization plasma volume returned to normal within three to four weeks When five physically active young men in good physical condition were confined to bed for three weeks the decrement in plasma volume (T 1824) averaged 518 cc or 15 5 percent (88) Within the first week of reconditioning (daily grade walking and running), plasma volume returned to pre bed rest values At the end of the first week of reconditioning blood volume remained slightly diminished due to an apparent loss in red blood cells (see section on training) The plasma volume change was ap

good' physical condition

normal young men (pre

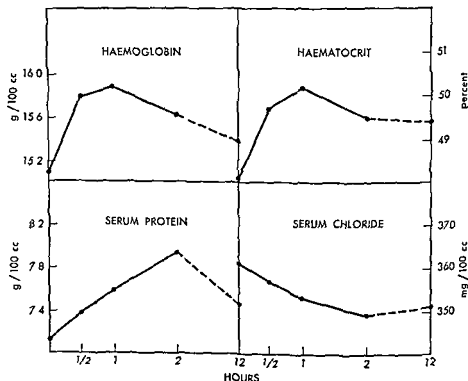
immobilization study The

difference in physical conditioning may have been responsible for the difference in the plasma volume decrement observed

POSTURE

When a standing subject lies down, his plasma volume increases Waterfield (94) found that standing decreased circulating plasma volume 15 percent and decreased red cell volume 4 percent Blood volume totals were 5244 cc in a horizontal and 4732 cc in a standing position or a decrease of

6 percent Aull and McCord (4) found that the concentration of serum protein (phosphate turbidity measurement) averaged 0 8 g /100 ml more (an 11 percent increase) when medical students were ambulatory than when they rested in bed A complementary experiment (75) was done on 30 pregnant, ambulatory women At the end of one hour of supine rest (following a walk) a significant decrease (from the value at the end of the walk) was found in the concentrations of total protein, albumin, and globulin in the blood Since the capillary walls are relatively impermeable to the serum proteins, this implies that when supine, there is usually a water shift from the interstitial fluid to the plasma Widdowson and McCance (97) determined a dynamic picture for this water shift which appears in Fig 11 2



Although the above studies present similar qualitative results, they differ quantitatively With the exception of Waterfield s work, the data are indirect, nevertheless, the increase in concentration of the larger molecules in the blood with standing (and simultaneous decrease in concentration of the

Cl ion, which travels readily with water and available cations) is most easily explained by a temporary loss of plasma water which slowly returns from the interstitial space with continued standing This effect of posture should be recognized and considered in the interpretation of fluid shifts attributed to a particular type of exercise

ACUTE EXERCISE

This section is devoted to the effects of a single bout of exercise (acute exercise) on the transfer of water from one compartment to another The pre 1940 literature has been reviewed (44) and should be consulted by the interested reader

Hematocrit, blood hemoglobin, and serum protein concentrations usually increase with exercise Hemoconcentration during exercise reflects the loss of a relatively protein free fluid from the blood and not an increase in the volume of red cells (55) The loss of fluid occurs largely at the expense of plasma volume Hemoconcentration from release of concentrated sequestered blood stores is probably relatively unimportant in exercising man (66) Splenic contraction, which adds blood rich in red cells to the circulation, takes place in exercised dogs and cats, but has not been observed in humans during exercise (23,27)

During light and moderate work, the observed hemoconcentration (hematocrit and plasma protein) and reduction in plasma volume is only slightly greater than during prolonged standing (16 44) However, during severe exercise considerable hemoconcentration and reduction in plasma volume have been found (44,45) While a minimum duration of work is required to elicite measurable hemoconcentration, work continued beyond this minimum may not alter hemoconcentration appreciably (41) and in fact may result in return to the pre-exercise values unless dehydration accompanies the work (1,89) Thus hemoconcentration may increase initially with the start of exercise and then gradually return to initial values unless dehydration ensues

Table 11 2 summarizes information showing the decrease in plasma volume with short term exercise (five minutes to one hour) Studies in which the exercise varied from light to extremely severe were selected to present the range of hemoconcentration and plasma volume reduction observed when exercise is varied in intensity [2]

[2] In many studies measurements were made of both the increase in plasma protein and T 1824 concentration due to exercise The decrease in plasma volume, estimated from the change in concentration of T 1824 was much larger than that estimated from plasma protein The usual T 1824 procedure has involved comparison of the dye concentration in the postexercise sample with that assumed to exist (at the moment) in pre exercise blood as calculated from the rate of disappearance of the dye A small error in estimating the pre-exercise value from the slope of the disappearance curve (particularly when the postexercise dye concentrations have been measured from one to three hours postin

TABLE 11 2. Change in Plasma Volume as a Result of Acute Exercise of Various Intensities

Type of Work	Severity	Duration, Minutes	Plasma Volume Change (Pr)[a]	(T-1824)[b]	Reference
Walking	3 5 m p h , 10% grade	15	10 0	12 9	Cassels & Morse (16)
Running	6 7 m p h , 8 6% "	2–5	12 4	16 3	" "
Bicycle	400 kgm /min	10	12 5	13 3	Kaltreider & Meneely (44)
Bicycle	Ride to exhaustion	5 5	21	21	" "

[a] (Pr) = decrease in plasma volume as calculated from plasma protein concentration change, in percent of the preexercise value
[b] (T 1824) = decrease in plasma volume as calculated from T 1824 concentration, in percent of the preexercise value

In competitive lumberjacking, one of the most severe forms of protracted work, hemoglobin and erythrocyte concentrations were reduced as a result of a whole day of work (46) During the night, following the day of lumber jacking, partial recovery frequently occurred If partial recovery during the night did not occur, the lumberjack could not continue at the same rate of work the next day Concentration changes such as these probably do not reflect plasma volume changes, however, it would be interesting to know what, if any, changes in plasma and red cell volume occur during lumberjacking activities

jection) may result in a large error in the estimate of plasma volume More important, Ebert and Stead (25) report that the optical density of the plasma sample measured postexercise is unexpectedly high This is due not only to the increased dye concentration (associated with the exercise induced plasma volume change), but also an increase (of up to 40 percent of the total change) in the optical density of the dye free plasma

ue exclusively to dilu
cause overestimation
asured by colorimetry,
by colored impurities
during sample collection, hemolysis,
or lipemia Accuracy can be improved by quantitative extraction of the dye from the
), or the addition of a detergent

1824 and the exercise sample, the plasma volume estimated by T 1824 concentration corresponds more closely to the volume estimated by plasma protein concentration (44) No distinct advantage is apparent in using T 1824 (rather than plasma protein) concentration to estimate the change in plasma volume with exercise Plasma protein concentration probably mirrors the change in plasma water unless a change in protein metabolism occurs, e g, circumstances which produce a negative nitrogen balance such as dehydration (69) To our knowledge, the newer techniques for labeling red blood cells or components, i e, Cr^{51} (86), Fe^{55} or ^{59} and P^{32} (10) have not been used to confirm the indirect observation that the red blood cell mass is relatively unchanged as a result of exercise

Only limited and somewhat controversial information is available on the change of extracellular fluid, especially interstitial fluid, with exercise. Cullumbine and Koch (19) studied 13 Ceylonese adults who were asked to step up a 20-inch step at the rate of 30 cycles per minute for 5 to 10 minutes. This work was accomplished readily and was therefore labeled as moderate by the authors. A mixed injection of T 1824 and NaSCN was administered prior to stepping. The exercise was performed between 20 to 40 minutes after the injection. Plasma volume decreased 225–800 cc while SCN space and interstitial fluid both increased. The increase in interstitial fluid was greater than could be accounted for by plasma water loss. The experiments were repeated using an injection both before and immediately after the exercise with the same result. The peak value for interstitial fluid occurred somewhat later than peak hemoconcentration. This finding suggested that the interstitial space had gained fluid from the cells. In recent experiments on oarsmen who rowed at a high work rate (0.58 h.p. for 6 minutes), no change in thiocyanate space was observed as a result of the work (55). Although plasma volume was considerably reduced (0.6–1.9 liters) by the rowing, the efflux of plasma water was apparently taken up in the interstitial spaces.

MECHANISMS

The loss of relatively protein free filtrate (some protein is lost, see below) from the vascular system during exercise is probably due in part to the increased intravascular hydrostatic pressure which accompanies exercise. Peripheral, mean arterial, and venous pressures are usually elevated during exercise from the increase in cardiac effort. The elevated intracapillary hydrostatic pressure, which must accompany the increase in mean arterial and venous pressure, is apparently sufficient to effect a net transfer of water from the vascular to the extravascular compartment (77,91). The correlation between increases in brachial arterial and venous pressure and decreases in plasma volume has been reported to be small (16,44). However, that portion of transcapillary water flow which is due exclusively to hydrostatic pressures depends on the effective transcapillary pressure difference. Since the observation of brachial pressures does not reveal the value of this gradient (particularly in parts of the body other than the arm) brachial pressures may be of little value in explaining vascular fluid loss.

At least two other findings are important in a discussion of water loss from the vascular system during exercise. First, a change in vascular wall permeability probably occurs because a small protein loss to the extravascular fluid (22,58) and through the kidney (65) accompanies the water loss (1 percent of filtrate estimated as protein [49]). When protein is lost, effective osmotic pressure in the peripheral vascular system decreases (49). Second, perhaps cells that are metabolically active become hyperosmolar (81), particularly if hypoxic conditions exist in the cells (78). For example, electric

shock convulsions (96) as well as respiratory hypoxia (3) result in shift of water into cells Thus both processes would favor transfer of water from the vascular system and supplement the effect of increased vascular hydrostatic pressure As H_2O is lost, plasma protein concentration increases, which elevates plasma osmotic pressure with the result that the rate of plasma water loss is curtailed In addition, during severe exercise free calcium may be restrained from diffusion, resulting in a net increase in osmotic pressure (47) Other factors than those mentioned contribute to the removal of water from the vascular system during exercise Precise quantitation of their contributions remains to be accomplished

During exercise the muscles pump lymph through the lymphatics at a rate presumably related to the severity of physical activity This lymph enters the vascular system and the contained protein is added to that already in blood, thus contributing to serum concentration In dogs, the rate of flow of thoracic duct lymph may be increased threefold or more over the resting rate with moderate exercise such as treadmill walking (29) The total contribution of lymph protein to blood in the dog is still insufficient, however, to explain the increase in serum protein concentration observed following exercise The relative contribution to hemoconcentration, at various exercise levels and/or fluid exchange, remains to be evaluated particularly in man

The body responds in a dynamic fashion and several mechanisms simultaneously affect fluid shifts in exercise The mechanisms may be altered with

CHRONIC EXERCISE

Training

The term *training* is used to describe exercise repeatedly undertaken for a specific purpose (preparation for a mile race) and includes short term *physical conditioning* (an exercise program undertaken for a month or two to improve work capacity) Training is not meant to include an exercise program which is followed for years, this being covered in the section on "habitual exercise," although the effects of sustained training and habitual exercise may be similar

Blood Volume

The effects of training on blood volume reflect changes in both plasma volume and red cell volume There is some disagreement as to specific changes in these volumes brought about by training Kjellberg (50,51) and

Sjostrand (82) reported that people trained in competitive sports showed a significantly higher (41–44 percent) total hemoglobin (carbon monoxide space CO) and estimated blood volume than people not specially trained However, little change in hemoglobin content per unit volume of blood was noted between the untrained and trained people They reported a qualitatively similar finding (10–19 percent increase in total hemoglobin) in four adults who skied nine days at altitude In interpreting these studies the following should be considered the ultimate fate of CO in the body is not actually known CO is taken up by myoglobin as well as hemoglobin and total myoglobin increases with training (61,18,93), also, altitude has been found (7,42) to increase red blood cell volume, hemoglobin concentration, and to increase total myoglobin (18,93) in the absence of training A combination of exercise and altitude exposure summate to a limited extent What may happen with training is an increase in muscle and myoglobin mass with a perhaps parallel, but unknown, increase in total circulating hemoglobin

In a recent study, no significant change was found in plasma volume (T 1824), blood volume [T 1824 space/(1 hematocrit)], or red cell volume in five soldiers who underwent three weeks of physical conditioning (cross country running and organized exercise, 8)

In neither of the above studies was the day to-day variation observed However, the day to-day variation has been followed in dogs (Fig 11 3, 20) In dogs, training produced an initial reduction of erythrocyte concentration, hemoglobin per unit volume of blood, and blood volume (CO method) As training was continued, these values not only returned to, but exceeded, the pre-exercise values and then returned to pretraining values as shown in Fig 11 3 Similar observations of changes in hemoglobin concentration with intensive training were observed in one man (2) The hemoglobin content per red blood cell may be low throughout training or return to normal (90)

Several mechanisms may affect the changes (2 90) of the blood picture with exercise With the onset of intensive training, there is an increased rate of destruction of red blood cells (90,2) with a resulting initial decrease in red blood cell concentration This is followed by release of immature erythrocytes which restore the red blood cell count, but the young cells are relatively *deficient in hemoglobin* This leads to a reduced Hb/r b c ratio (4 to 14 percent, 2) while total hemoglobin may not change appreciably As training continues erythropoiesis may proceed at a relatively high rate and then decrease to a new equilibrium In addition to the above processes, the effects during training of the endocrine glands on the rates of production and release from hemopoietic tissues of the formed elements of the blood deserve elucidation

The changes with training in fluid volumes other than blood volumes have not been studied extensively Only one study was found in which extra

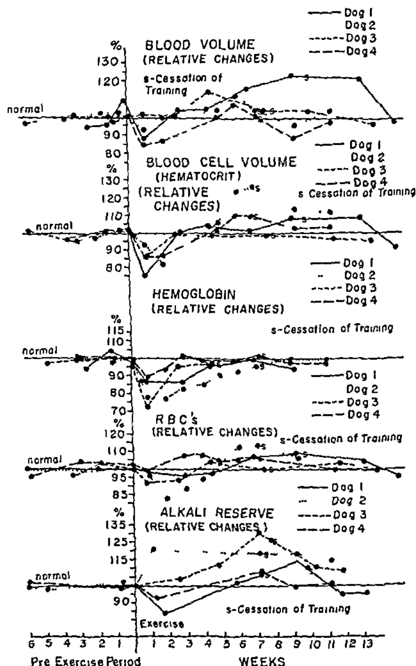


FIG 11 3 *Relative changes in various blood components during a period of physical exercise Dogs 1 and 2 were exercised by treadmill running at 25 percent grade for 6 miles daily Dogs 3 and 4 were exercised by swimming for two hours daily in water at 30°C Exercise periods lasted four to nine weeks and were followed by an observation period (Davis and Brewer, 20)*

cellular fluid (using radiosulfate) and total body water (using D_2O), were measured before and after a training regimen. In this study (70), various body composition measurements were made in 12 men before and after a 3 week paratrooper training course All had just completed a 12 week basic training course so that they were in reasonably good physical condition at the start of the study During the paratrooper training the step was presumably one from a good to a better state of physical conditioning for walking, running, lifting, and carrying The results are presented in Fig 11 4 Extra-

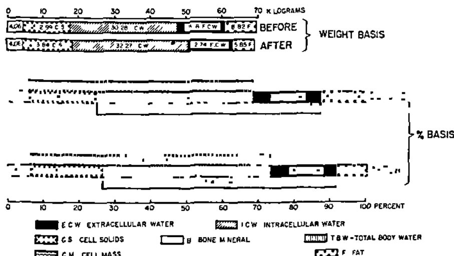


FIG 11 4 *Body composition of soldiers before and after paratrooper training Paratrooper training was of three weeks' duration*
Methods ECW radiosulphate space, TBW deuterium oxide space, ICW TBW − ECW, CM = ICW/0 7, CS = 0 3 CM, B = 0 134 ICW, F = estimated from body fluids (*Pascale*, et al, 70)

cellular fluid did not change Body fat decreased and fat free body weight increased Total body water also increased which meant that the increase in intracellular (total body water minus extracellular fluid) water was responsible for the increase in total body water and was related to the increase in fat free body weight (see Habitual Exercise section)

Though "cell mass" is presumably hydrated at a constant level (59), there are quantitative differences in muscle with training (92) which may mean that the training induces a change in hydration of the "cells" It is unlikely that the present methods for determining the relationship between "cell mass" (51) and its water content would clarify this point An independent method for determining any one of the following nebulous and interrelated items would be useful muscle mass, cell mass, active tissue, and lean body mass

HABITUAL EXERCISE

Habitual exercise is defined, for our purposes, as exercise engaged in for months, often for a significant part of the subject's lifetime. Several studies (95,11,13) have compared body composition data (including body fluids) from men who have habitually exercised with similar data from sedentary men. These data are presented in Table 11.3. The results show that habitual exercise is associated with a greater body specific gravity and/or density

TABLE 11.3 Body Composition and Activity Habitus (A Compilation of Three Studies)

	Study I Welham & Behnke (95)		Study II Brozek (11)		Study III Buskirk (13)			
Activity Habitus	Naval Personnel	Football Players	Habitually Sedentary	Habitual Exercise	Habitually Sedentary	Intramural Athletes	Varsity Athl.[a]	Runners
N	75	25	27	29	15	8	6	5
Av. age	—	—	52.2	52.9	22	22	21	20
Av. wt., kg	72.6	91.2	78.3	81.5	77.5	79.5	73.4	65.8
Density	1.074[b]	1.080[b]	1.044	1.049	1.057	1.075	1.091	1.080
% Fat[c]	12	9.4	27.2	24.3	16.5	9.4	3.6	7.7
% FF[d]	88	90.6	72.7	75.7	83.5	90.6	96.4	92.3
% TBW[e]	—	—	—	—	54.3	61.7[f]	61.1	—
% SCN[h]					23.9	25.4[g]	25.3	—
% ICW[i]					37.6	43.9	43.4	

[a] Varsity athletes: wrestlers, football players, and gymnasts.
[b] Specific gravity, not density.
[c] Calculation of percent fat from body density or specific gravity was different in each study. Therefore comparisons should be made between groups in a study rather than among studies.
[d] Percent fat free body weight = 100 − % Fat.
[e] Percent total body water (Antipyrine).
[f] N = 3.
[g] N = 4.
[h] (SCN space/wt.) × 100.
[i] Intracellular water = % TBW − 0.7 % SCN.

Since the density of fat is about 0.90 at 37°C (31) and that of 'cells' approximately 1.057 (48), the denser subject will have a proportionately greater fat free body weight, or 'cell mass,' than his less dense, obese counterpart. Fat contains 20–30 percent water (74), while 'cells" contain 65–75 percent (48,68). Hence, a greater percent of fat free mass is associated with a greater percent of total body water in the subject. This is shown in Fig. 11.5 (13). The results were obtained from three groups of students who varied with respect to the type and amount of habitual physical activity. The relationship between total body water and fat free weight does not appear to be modified by activity habitus (see later subsection).

A comparison of plasma red-cell, and blood volumes in the same groups of university students is presented in Table 11 4 No significant differences in any of the blood volumes were found between the groups no matter which unit of reference (total body weight or fat free weight) was used The athletic group was not accustomed to frequent bouts of exhausting exercise involving hypoxic conditions at the cellular level (perhaps the necessary stimulus to induce red-cell changes and hence changes in blood volume) The athletes were wrestlers, football players, and weight lifters

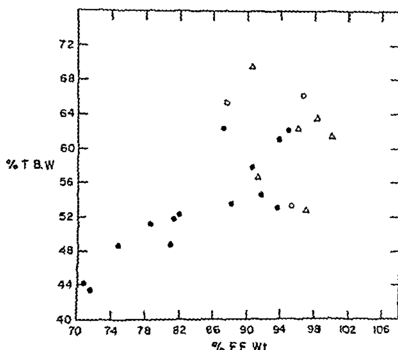


FIG 11 5 The variation in percent of total body water (% TBW) and percent of fat free body weight (% FFWt) in three groups of students varying in physical activity habitus (Buskirk 13)
• Sedentory O Intramural participants Δ Varsity athletes

Comparison of red-cell volume in relation to height and weight in prison inmates revealed that the inmates accustomed to considerable physical activity possessed only slightly larger red-cell volumes than the inmates with sedentary habits (10) It would be desirable to extend this work to cover the entire range of physical activities to clarify the impact, if any, of habitual physical activity on blood volume

Body fatness was inversely related to the extent of participation in physical activity, i.e., athletes averaged less fat than intramural participants who averaged less fat than sedentary students The proportion of cell solids'

TABLE 11 4 Comparison of Plasma, Red Cell and Blood Volumes Among Groups of University Students Varying in Physical Activity Habitus

Activity Habitus	No in Group	Plasma Volume[b]			Red-Cell Volume[c]			Blood Volume[d]		
		liters	% wt	% FF[e]	liters	% wt	% FF	liters	% wt	% FF
Sedentary	15	3 27 (2 60–3 90)[a]	4 32 (3 44–5 69)	5 16 (4 70–6 07)	2 85 (2 36–3 14)	3 79 (2 70–4 75)	4 50 (3 76–5 47)	6 10 (4 96–6 94)	8 11 (6 14–10 08)	9 66 (8 58–10 83)
Intramural sports	4	3 79 (3 37–4 45)	4 71 (3 93–5 19)	5 30 (4 99–5 94)	3 04 (2 85–3 44)	3 80 (3 04–4 38)	4 26 (3 92–4 59)	6 82 (6 36–7 89)	8 51 (6 97–9 33)	9 55 (8 90–10 53)
Varsity sports	6	3 54 (2 92–4 61)	4 85 (3 79–5 34)	5 07 (4 15–5 87)	2 90 (2 36–3 68)	3 96 (3 59–4 28)	4 14 (3 67–4 46)	6 44 (5 51–8 29)	8 80 (7 38–9 44)	9 22 (8 08–10 33)

SOURCE Buskirk (13)
[a] Values are mean values, followed by the range in parentheses
[b] Plasma volume was measured by T 1824
[c] Red cell volume = plasma volume (1 − hematocrit)
[d] Blood volume = plasma volume + red-cell volume
[e] % FF = percent of fat free body mass = volume/body wt (100% fat)

and fat free body weight was greater in the athletes than in students who were less active Total body water and intracellular water were proportionately smaller in the sedentary students than in the two more active groups No significant difference was noted in the fraction of extracellular water among the three groups (13) For related studies on animals the reader is referred to the work of Kohlrausch (54) and Mitchell and Hamilton (62)

DEHYDRATION

Dehydration frequently becomes a problem in athletics because (1) during severe work, sweat and respiratory water losses are usually high in most environments, (2) water losses frequently are not replaced, either because of the demands of the activity or beliefs on the part of coaches and trainers, (3) weight has to be "made' immediately before performance and opportunity may not be provided for sufficient water replacement, (4) coaches have been known to restrict daily water intake as well as diet to 'improve a training regimen Thus practical water balance problems arise in athletics which can arbitrarily be divided into two categories, acute and chronic dehydration *Chronic dehydration* denotes the negative water balance which is sustained for a day or more *Acute dehydration* denotes the negative water balance which occurs as the result of a single game, contest, or period of making weight

Acute Dehydration

Dehydration should be viewed as a potential source of debilitation in athletic events which require sustained high rates of energy expenditure and production of large amounts of sweat The interaction of a hot environment and hard work usually predicates considerable dehydration Marathon running and tennis matches in the heat are examples of situations favoring substantial body water losses Measurements of body weight loss (proportional to body water loss), pulse rate, blood concentration, and body temperature changes have been made in connection with athletic participation, as well as with field and laboratory research (1,6,14) The elevation of rectal temperature with exercise is directly proportional to the extent of dehydration (above a 2–3 percent body weight loss, 14,63) Hemoconcentration, as reflected by an elevation in hematocrit, and particularly by an elevation in plasma protein concentration, is produced by moderate exercise and associated dehydration (1,14) The extent to which dehydration supplements the hemoconcentration induced by various types of physical work or the duration of work is not settled (1,6) With dehydration during walking in the heat, the serum refractive index difference (which reflects change in total serum solid concentration) increased in proportion to the water deficit and reached values of about +25 percent with a 10 percent water deficit

(percent of initial body weight, 1) With acute dehydration during exercise, the changes in body fluid volumes may only be inferred Adolph (1) has estimated that with a dehydration loss of 6 percent of body weight, the plasma loses 15 percent of its initial volume Expressed as a proportional loss, i e, percent plasma loss/percent total body water loss, the ratio was approximately 5 2, indicating that percentagewise, more water is lost from plasma than from the remaining fluid volumes The red blood cells also lose some water Thus the circulating blood volume is reduced and circulatory deficiency ensues The elevation in heart rate is due to the circulatory strain Sweat rate continues unaltered (1) or perhaps only slightly diminished (10 percent) with acute dehydration (34) The continued loss of body sweat is the factor responsible for the reduction in the circulating blood volume

It is interesting to note the enhanced tolerance to dehydration by well conditioned individuals In well conditioned marathon runners who sustained 2 5–7 4 percent body weight losses during running, a performance decrement was not perceptible Running pace was maintained essentially constant and sprint finishes were frequently attempted and accomplished (14)

Further laboratory experimentation also indicated that physical conditioning for cross country running augmented ability to work in a 25 5°C (78°F) environment when dehydrated 5 percent of body weight These findings contrast somewhat with those obtained on men who become dehydrated in the heat In the heat, physical conditioning for walking did not particularly alter the commonly observed debilitating effects of dehydration of the order of 2–5 percent of body weight loss (1) Whether physical conditioning for running would enhance work performance when dehydration exceeds 5–7 percent body weight loss remains a moot question Dehydration of this magnitude may readily occur during distance running in the heat

Chronic Dehydration

Although chronic dehydration is not usually a problem in athletics, circumstances arise which may produce chronic dehydrations of unknown magnitude, i e, when weight loss is incurred by food and water restriction in order to make weight and when water restriction is enforced by coach or trainer as part of a training regimen Recent evidence (37,63) suggests that chronic dehydration affects the body rather differently from acute dehydration largely because compensatory mechanisms become established

Dehydration (accompanied by caloric restriction) was incurred slowly in a cool environment at a fixed level of water intake in men who performed hard work daily Water balance was restored in five days at 1800 cc a day water intake and was nearly restored in six days at 900 cc a day In this situation no decrement in work performance was observed although there was an increase in rectal temperature and pulse rate with dehydration Water conservation also occurred (decreased sweat rate, respiratory and insensi

ble water loss) Water conservation has not been noted when men work under conditions of high environmental temperature (56,71) Water conservation with chronic dehydration during hard work was achieved at least initially, by the elevation of body temperature during work In general, the rectal temperature response to work was higher the more dehydrated the individual, but the trend was not apparent until a negative water balance of −2 to −3 kg was reached The decrease in sweat rate as dehydration progressed may reflect an altered sensitivity of the mechanisms governing the response of the sweat glands to an elevation in core temperature Thus water is conserved at the expense of thermostasis—a response not unlike that found in the camel (79) Unfortunately, shifts in body fluids as a result of exercise were not followed during the course of the chronic dehydration experiments

Water Replacement

The natural correction of dehydration is impossible without the operation of the thirst mechanism The sensation of thirst in the exercising man is seldom sufficient to maintain adequate hydration

If possible, the individual should be given water to replace the water deficit, or, at least, limit it to the approximate 2 l of free circulating water postulated by Ladell (56) Further replacement may be unnecessary Replacement of loss should also include replacement of the salt This is usually best accomplished by adequate salting of food (see chapter 17)

One interesting example illustrating the importance of adequate water replacement in the face of potential dehydration is that found in mountaineering Only limited amounts of water are usually carried on expeditions Unless snow is eaten directly, water must be prepared by melting ice and snow—a tedious task which is frequently avoided at altitude Water loss from the body occurs at a relatively rapid rate because of the increased ventilation volume and the large vapor pressure gradient between body surfaces (skin and lungs) and the ambient air The success of the Mt Everest expedition in 1953 may have depended in large measure on provisions for insuring adequate water for the climbers (59)

HEMORRHAGE

The immediate effect of rapid hemorrhage (of 500 cc) is a decrease in
pendent on the
plasma occurs
both blood gas
transport capabilities and cardiovascular dynamics, i e, stroke volume, heart rate, venous return, vasoconstriction, etc, at a given exercise level The blood volume deficit is gradually restored by the influx of water from the interstitial fluid and perhaps intracellular spaces The plasma volume may

revert to normal within 24 to 48 hours and may exceed normal within a week or more The red-cell concentration and volume is restored more slowly and may take three to six weeks to regain the prehemorrhage level (27)

Determination of the effect of blood loss on physical performance has been attempted in at least three ways by assessing (1) the pulse rate response to a fixed work load (84), (2) the time to exhaustion at a fixed work load (45), and (3) the response of several physiological variables, i e, heart rate, blood pressure, maximal ventilation, etc, during the performance of a continually increasing work task (5) The results obtained in these

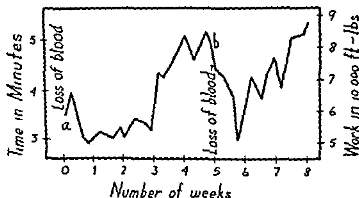


FIG 11 6 *Effect of hemorrhage on work capacity Subject J L, working on a bicycle ergometer at a rate of 0 507 horse power, 117 pedal revolutions per minute Point (a) indicates loss of 500 cc of blood for transfusion and point (b) a similar loss five weeks later It took three weeks to recover completely from the effects of the loss of blood (Karpovich and Millman, 45)*

studies support the view that work performance is reduced for one or more days following hemorrhage, however, the results cited do not necessarily present a clear and consistent picture

The fact that pulse rate is higher during the performance of work *after* hemorrhage (84) only reflects the change in cardiovascular dynamics and may bear little relation to aerobic capacity, total work capacity, or other indices of performance (88)

Since the subject in the study mentioned under (2) was a well trained athlete (athletes may recognize their work capacity more readily than non athletes), motivation may have been maintained at a high level so that the decrement in length of work after hemorrhage reflected at true decrement in work performance The shape of the work performance curve (see Fig 11 6) after each of two hemorrhages, and the variability of the length of time worked from day to day implies, however, that motivation had an equal or greater impact on the performance curve than hemorrhage Examples of

collapse and poor performance in athletic events after hemorrhage may provide better evidence of decreased physiological rather than psychological capability (45)

Balke and others (5) have determined what they term 'optimal work capacity' after hemorrhage Interpretation of the records for pulse rate, systolic blood pressure, ventilation volume, etc, provided end points for cessation of the test The test consisted of walking at 3 5 m p h on a tread mill, the grade of which was increased ½ percent of belt travel per minute Table 11 5 gives the time in minutes at which specific physiological events related to "optimal work capacity occurred on the average for the group of

TABLE 11 5 Sequence of Critical Events, Before and After Hemorrhage (500 cc), When Work Load Exceeds "Optimal Work Capacity
(Average values giving time of occurrence in minutes after the start of exercise[a])

	Controls[b]	2–3 Days[c]	8–10 Days[d]
Pulse rate 180	28 7	26 5	30 8
Respiratory exchange ratio > 1	28 7	26 4	30 7
Oxygen pulse maximum	28 0	26 5	30 8
Alveolar pCO_2 falls	28 0	27 5	30 8
Respiratory rate rises	28 0	26 5	30 6
Pulse pressure maximum	30 0	26 5	30 8
O_2 intake maximum	30 8	28 5	32 7
Tests terminated	31 5	29 0	33 8

SOURCE Balke *et al* (5)
[a] Exercise treadmill walking at 3 5 m p h slope was increased ½% of belt travel per minute
[b] Controls hemorrhage
[c] 2–3 days posthemorrhage
[d] 8–10 days posthemorrhage

14 men studied From these data, the authors concluded that 'optimal work capacity" was significantly reduced at one hour after hemorrhage Results obtained at 48 and 72 hours (2 3 days) after hemorrhage were not significantly different from control values, while at 8–10 days after hemorrhage, a statistically significant improvement in optimal work capacity over the control prehemorrhage value had occurred (Data of Karpovich and Millman [45] do not support this latter observation) The authors explain the improvement in optimal work capacity at 8–10 days after hemorrhage as due to the overrestitution of the plasma volume, which leads to a larger circulating blood volume This explanation is supported by the observation of a lower pulse rate when performing at a fixed work level after venous infusion (84)

Although the results presented are somewhat inconsistent, they do illustrate a general decrease in cardiovascular "reserve" after venesection which is restored in from five days to three weeks later. One interesting question has not been answered by the work cited How does hemorrhage influence ability to deliver oxygen to working muscle, particularly at severe work levels? In other words, how is the maximal oxygen intake altered? Total circulating hemoglobin is reduced after a 500 cc. venesection by about 7-10 percent Is a decrement of this magnitude sufficient to reduce aerobic capacity? The maximal oxygen intakes in the hemorrhage experiments reported by Balke, *et al*, are well below the levels commonly measured by a test designed specifically to assess maximal oxygen intake (88) It has been suggested that aerobic capacity is dependent on total circulating hemoglobin (52,53). hemorrhage would afford a good opportunity to investigate this premise and to give further insight into factors limiting aerobic capacity.

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The Effects of Exercise upon the Function of the Gastrointestinal Tract

SUMMARY

The involuntary muscle of the stomach walls contracts actively and rhythmically during the digestion of a meal, and in some people, when the stomach is empty or nearly empty In the latter case the activity gives rise to hunger pangs Mild exercise such as walking is generally without influence on the stomach contractions, occasionally it may be stimulating Severe and exhausting exercise usually depresses the stomach activity, but following the exercise there may be a rebound of activity to greater than usual During violent exercise following a meal the human subject may have distress referable to the abdomen which may culminate nausea and vomiting

Much work has been done to determine the effect of exercise upon the production of the digestive secretions in the stomach where the food first begins to be acted upon by digestive enzymes In general, the effect of light or moderate exercise before or after a meal is to leave the secretory function unchanged, although, as with the contractions, there may be stimulation Severe and exhausting exercise reduces the secretions of the stomach This may be brought about by competition of the active voluntary muscles for blood, by a chemical substance released into the blood by the muscles or elsewhere, or by both The psychic state of the person may play a part as well

Very little is known about the effects of exercise on the pancreas, the liver, or the small and large intestines In general, moderate exercise seems to be without effect In one study repeated daily exercise stimulated the contractions of the small intestine which are responsible for propelling material through them

Finally it is concluded that exercise when moderate permits the digestive

tract to function normally Severe exercise following a meal may produce alterations in digestive function such that the rate of doing work may be limited, but thanks to a large margin of safety, one cannot say that permanent harm to either digestive or voluntary muscle function has occurred

THE SALIVARY GLANDS

Donaldson (18,19,20 21,22,23) has made an extensive study of the effect of exercise on the weights of various organs of albino rats If instead of restricting rats to a sedentary cage life they are provided with a revolving drum for voluntary running, many changes occur Among these is an increase in wet weight of the submaxillary salivary glands The increased size of the gland is due to the presence of cells with increased dimensions, and possibly also to an increased number of cells It is not known whether the enlargement is brought about by the exercise *per se* or by secondary effects such as increased appetite and food consumption

GASTRIC MOTILITY

The activity of the stomach may be somewhat arbitrarily divided into a motor and a secretory function The motor function is based upon the activity of the smooth muscle in the walls of the stomach This activity may consist partly of tone, a maintained but slightly varying tension upon the contents of the stomach, and partly of more intense intermittent contractions which constitute hunger and digestive motility

Gastric Hunger Contractions

Hunger contractions of the empty or nearly empty stomach have been customarily studied with the use of balloons—either introduced into the stomach by way of an esophageal tube in intact man or directly through a gastric fistula opening—and inflated later in man as well as in animals The hunger contractions were first extensively studied by Cannon (11) and by Carlson (12), both of whom, as has recently been shown, probably exaggerated their role in the production of the phenomenon of hunger (27)

It would seem that the present view of the gastric hunger contractions relegates them simply as the cause of the gastric component of hunger (hunger pangs) in a relatively few persons If they serve any further function, no certain proof has been forthcoming The effect of exercise upon this phase of gastric activity might seem, at first glance, therefore merely academic However, since the effect of exercise upon other components of gastric function is still disputed and not clearly understood, it will be profitable to consider the effects of exercise on hunger contractions

Carlson made his studies of this problem on both dogs and man Dogs with simple gastric fistulas, and which ran willingly on the treadmill, were

used The dogs were studied for two to four hours after a day's fast Running *on the treadmill was always inhibitory to both tone and hunger contractions* The higher the speed of running, the greater was the amount of inhibition However, if the exercise (four to six miles of brisk walking outside the laboratory) preceded the recording of contractions no effect could be seen

In five human subjects the effects of standing and of walking or running in place were observed, and also the effect of previous exercise Neither standing nor wa
promptly inhibi
found in the dog
human cases, the confirmation probably rules out emotion as the cause of the inhibition in the dog

The effects of exercise immediately prior to the recording session was made in man after playing tennis or walking six to twelve miles The impression was given that if the exercise was moderate, there was increased tone *and hunger contraction activity, but that if exhausting fatigue were present* there was a tendency toward inhibition

GASTRIC DIGESTIVE MOTILITY

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tents, but also to move the contents on to the duodenum, the rate of gastric emptying reflects the effectiveness of this activity

Campbell, *et al* (10) in 1928 were apparently the first to make a quantitative study of the rate of gastric emptying as affected by exercise They used a modification of the Boas meal (oatmeal gruel) as a test meal On the basis of volume of gastric contents and concentration of reducing sugars and also of percent of solids at the end of one hour they calculated the per cent of the meal remaining in the stomach From this value it can be determined that severe exercise, as in running 1–4 miles, in 7 different men pro-

whose slope served as a measure of rate of gastric emptying
pearance of the shadow gave another measurement—the gastric emptying time

produce a normal gastric emptying time It is not known what might have

happened if the exercise had continued unabated throughout the time the meal was in the stomach, but it seems likely the consequences might have been quite uncomfortable

In another study in which gastric motility was recorded by means of an intragastric balloon, mild exercise was seen to have no effect, but more severe exercise was depressing (31)

In summary, the studies of the effect of exercise on gastric motility show that as a rule mild or moderate exercise is generally (although occasionally stimulating) without effect, but that violent or exhausting exercise is definitely inhibitory

GASTRIC SECRETION

There are present in the wall of the stomach three or four different types of gland cells In the body of the stomach are found the gastric pits leading into simple branched glands The predominant cell here is the chief cell which elaborates pepsinogen, which is the inactive precursor of the proteolytic enzyme, pepsin Also present is the parietal or oxyntic cell Its function is to secrete nearly pure hydrochloric acid in a solution whose osmotic pressure is the same as that of the blood plasma At the entrance into the gastric pits there are gland cells which secrete an alkaline mucus Other mucus secreting cells are present in the cardiac and pyloric glands The presumed function of the mucus is to coat the inner lining of the stomach in order to protect it from the corrosive action of hydrochloric acid and pepsin Since gastric juice is made up of the contributions from several different types of gland cell its composition is not necessarily constant

Little is understood of the control of the secretion of mucus in the stomach It is known simply that the presence of irritants such as eugenol calls forth copious amounts of mucus

Gastric juice produced in connection with meal taking is controlled in two phases The reflex or psychic phase initiates gastric juice rich in pepsin and hydrochloric acid The vagus nerve is the path by which impulses are discharged to the proper gland cell The impulses are called forth in the act of eating in response to stimulation of taste, smell, and enjoyment of the meal

After food is present in the stomach further secretion of gastric juice is maintained by a humoral factor which may be gastrin, the long postulated gastric hormone The presence of food causes the elaboration of a chemical agent within especially the pyloric mucosa which reaches the appropriate gland cell (chiefly parietal) by way of the blood stream

As a result of these phases of gastric secretion gastric juice is present in increased amounts just before or at the eating of a meal, and there is continued secretion as long as food is present due to the activity of the humoral factor

The way in which exercise affects gastric secretion was the subject of investigation well before the modern views as well as modern technics were prevalent For a summary of the early work one may consult the paper of Bridzius (9 in German) Hammar and Öbrink (28) give a résume of the more pertinent research efforts of the time in English These efforts appeared as early as 1849, somewhat after Beaumont, the American pioneer in gastric physiology, had made his classic observations on his patient with the gastric fistula

In all of the early, and even in some of the recent work, the presence of a test meal made it impossible to determine clearly what changes had occurred in gastric secretion as a result of exercise Also in much of the work there has been no quantitative measurement of the severity of the muscular exercise The predominant interpretation of the results of the early experiments was that severe and exhausting exercise performed during the presence of a meal in the stomach was inhibitory in both dogs and in man A few reports to the contrary were also made In these either no change had occurred or else the exercise augmented the secretion of gastric juice As to the effect of previous exercise upon the secretion there was the nearly unanimous conclusion that no change was forthcoming

The use of a Pavlov or a Heidenhain pouch, on the other hand, permits the collection of uncontaminated gastric juice Six studies have been made on dogs with such preparations

Pavlov Type Gastric Pouch Experiments in the Dog

The earliest reported work was by Kadygrobow, and was described in a dissertation in 1905 (9 28) He found that there was no effect of exercise taken prior to the feeding However, if the exercise came after the meal there was an initial phase of hyposecretion which, however, was compensated for by a later hypersecretion If the rate of doing the work were increased gradually the early inhibition could be eliminated

Bridzius reported in 1926 his results with two Pavlov pouch dogs (9) The [illegible]

[illegible] tion with heavy work and even moderate inhibition from just walking

Crandall (1928) used three Pavlov pouch dogs and exercised them after a mixed meal for one half to 1 hour on the treadmill (14) The exercise was [illegible] th the [illegible]

However, following the work there was usually a rise above normal which tended largely to compensate for the hyposecretion during the actual exercise

Prikladowizky and Appollonow (40) reported their results on two Pavlov

pouch dogs and in one dog with esophageal and gastric fistulas in 1930 The dogs were run on the treadmill at the rate of 205–225 meters per minute (7 64–8 39 m p.h) for 30 minutes following a meal of bread or meat In such experiments it was found that there was almost complete inhibition of the volume secretion of gastric juice during the run and for 30 minutes afterwards Following this period of initial inhibition there was an active period of secretion in which the rate practically paralleled the control rates obtained with a meal not followed by running It appeared to the authors that it was the reflex phase of gastric secretion which was mainly inhibited To decide this point, recourse was had to the dog with combined esophageal and gastric fistulas In such a dog a sham meal may be used and only the rate of secretion during the reflex phase measured No food reaches the stomach to elicit the humoral phase of secretion It was found that in such a dog exercise prevents any significant secretion when it follows the sham meal It also interrupts secretion once started if exercise is begun some time after the meal These results bore out the author s supposition that it was mainly the reflex secretion that was affected by exercise

HEIDENHAIN TYPE GASTRIC POUCH EXPERIMENTS IN THE DOG

In the remaining two investigations, dogs with Heidenhain pouches were used Since in the preparation of such pouches, the branches of the vagus nerves to the pouch are interrupted, only the humoral phase of gastric secretion is followed by the pouch

In 1948 Lilhehei and Wangensteen studied the effect of treadmill running on the histamine induced secretion in two dogs (37) A consistent depression of the volume of secretion during exercise was the predominant result In spite of the depression of gastric secretion it was found that exercise in 15 dogs chronically injected with histamine base-in beeswax markedly increased the incidence of ulcer formation These paradoxical results were interpreted as a demonstration of the importance of vascular changes as well as abnormal secretion in the genesis of gastric ulcer

The most recent work has been done by Hammar and Öbrink (28) Their dogs were run 30–60 minutes on the treadmill at the rate of 6 14 km /hr (3 82 m p.h) Gastric secretion was induced by either histamine or by feeding a meal of bone-dust in meat Exercise invariably produced a rather *prompt inhibition of the volume secretion rate of the Heidenhain pouch* If the severity of the exercise were increased, as by introducing a grade by tilting the treadmill, there was a correspondingly greater inhibition Although rectal temperatures rose 1.0–1 5°C no parallelism existed with the gastric changes, and consequently it was concluded that temperature changes were not responsible for the results If 50–75 ml of blood from an exercised dog were transfused into a resting dog which was actively secreting there followed a period of inhibition following the transfusion The authors concluded that in order to produce such results a chemical substance must increase in

concentration or appear *de novo* as a result of exercise, and that this substance must interfere with metabolic processes in the gastric mucosa

HUMAN EXPERIMENTS IN GASTRIC SECRETION

Although the methods for estimating gastric secretion are by necessity inferior in the human being, the results, such as they are, are much more pertinent For a critique of these methods the reader is referred to Hellebrandt and Brogdon (29) The technique requires either a test meal to be eaten by the subject or an injection of histamine to be made Samples from the stomach are obtained by introducing a soft rubber tube of small diameter and withdrawing gastric contents by appropriate means Introduction of the tube in the unaccustomed subject is not without considerable psychic trauma

Bridzius (9) briefly refers to the work of Streng (1890) and of Sping (1892) who studied the effect of exercise using test meals in men The former found no changes in gastric function as a result of exercise, while the latter found evidence of suppression of gastric digestion, particularly with hard work

Delhougne (16) in 1926 reported his studies on four young persons using the alcohol test meal Gymnastic exercise and stair-climbing for an hour and a half was found to be accompanied by greater increases in total acidity compared to control periods

Campbell, *et al* (10), studied the effects of running one to four miles in seven men The test meal was a modified Boas meal of oatmeal gruel At the end of one hour in the exercise tests free acid was practically nil, while the amount of total acid was reduced by nearly half on the average The authors reported that a psychic component was apparent Inhibition was not present if the running was not disliked or did not produce discomfort The latter condition depends, of course, on the fitness of the subject

The most extensive studies on gastric secretion in exercising human beings have been conducted by Hellebrandt, *et al* (30,32,33) In the first study the Ewald test meal (toast and tea) was used, and varying grades of exercise on the bicycle ergometer performed by four young women Gentle exercise before or after the meal augmented gastric acidity, but exhaustive muscular exertion, whether it preceded or followed the test meal, was associated with a diminution of acidity below normal This decrease was greatest when associated with emotional excitement as was found in five other women who engaged in a competitive sport (final game of a basketball tournament)

In a second study using the Boas (oatmeal gruel) meal in two young women, the same sort of results was found Using the presence of starch in the
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not necessarily be related to decreased secretion, but to dilution by stomach contents kept back by delayed emptying (Later confirmation of delayed

emptying in exhaustive exercise was accomplished as described on p 242)

A further study on three or four young subjects using the alcohol or the arrowroot cookie test meal revealed the interesting finding that the early hypoacidity in a work period would disappear with the repetition of all but extreme grades of work In the paper reporting this work the significant statement is made in *tube conditioned subjects* emotional stress severe enough to induce dryness of the mouth and palpitation left the acid secreting power of the stomach essentially unaltered

Finally Wolf and Wolff (51) report that in their man with a gastric fistula moderately violent exercise on (presumably) a fasting stomach brought about no detectable change in gastric function

The general impression from all types of exercise experiments in both dogs and in human beings is that light or moderate exercise before or after a meal either does not alter the response from normal or else actually increases the secretory function of the stomach Work of more severe character particularly exhausting in quality almost always depresses this function A similar effect on the motility function has already been noted (p 238) But in the human studies the presence of a psychic component associated inadvertently within the design of the experiment or else deliberately introduced may at times exert an inhibitory influence The question whether a similar component is present in the dog experiments is an important one but it is difficult to answer As Gregory (26) has recently suggested the findings inevitably call to mind the work of Verney and his pupils on the release of antidiuretic hormone from the pituitary by exercise and other emotional stress However a more critical analysis of the last mentioned work along with that of Cutting *et al* (15) and of Gray *et al* (25) reveals a major flaw in this approach The former authors found that it required 20 units/kg of pituitrin to inhibit markedly histamine induced secretion of gastric juice in the rabbit and 1 0–2 5 units/kg in the cat The latter authors found that it required 4 units per animal to produce a 53 percent inhibition of histamine provoked secretion in dogs with pouches of the entire stomach while in order to produce a striking antidiuretic effect in the course of water diuresis 0 001 unit per animal sufficed Rydin and Verney (41) had previously shown that the dose of pituitary extract required to simulate the antidiuretic effect of emotion (due to running on the treadmill or to frightening or angering with noise) in dogs was of the order of 0 0001–0 0005 units per animal The great disparity in the doses required to inhibit secretion on one hand and antidiuresis on the other makes it very unlikely that the pituitary principle is involved in the exercise inhibition of gastric secretion

SPLANCHNIC BLOOD FLOW

The mechanism whereby severe exhausting exercise might interfere with the function of organs of the splanchnic area has been variously hypothesized The prominent views which have been suggested over the years have

been (1) reduced blood flow due to redistribution of blood to the active voluntary muscles, (2) rise of body temperature, (3) changes in constituents

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more, in their transfusion experiments they found evidence which strongly suggested the third Hellebrandt, *et al*, found improved responses to exercise with repetition of experiments which suggested the disappearance through familiarity of an emotional component However, this observation was qualified by the statement that normal gastric secretory function has also been observed in the face of prominent activity of the sympathetic division of the autonomic nervous system There remains the task of considering the first as a possible source of malfunction However, it should be taken as a working principle that it would be quite unlikely for a single cause to play the sole role It would be more consistent with our modern conception of physiology to find causes working in concert as well as differently in different individuals and/or species and at different times

Local ischemia in the digestive tract, according to the historical review of Bridzius (9), was early postulated as a concomitant of exercise This viewpoint has had an assiduous opponent in Sjostrand and co workers who since 1934 have found evidence which at least challenges the old view The main points of attack have been the idea of reservoir function of the abdominal viscera for blood and the depletion of the store in exercise The extent of the circulation of the livers of mice was determined on the basis of the area of blood vessels filled with erythrocytes stained with benzidin or orthotoluidin in histological cross sections of tissue (42) It was found that after the exercise of running, the extent of the vessel area had more than *doubled* as compared with controls at rest The increase after the injection of adrenaline was even greater The more recent work of Sjostrand (43 44, 45), on the basis of partition of storage blood between the lungs and the splanchnic area, seeks to confirm the thesis that the latter is not a storage area On good grounds, Asmussen and Nielsen (2) have recently criticized the interpretation of the data thus presented For a review of the physiologi

defined

Furthermore, as Herrick, *et al* (35) have pointed out, vasoconstriction in the splanchnic area need not necessarily reduce the flow of blood there provided that there is a sufficient increase in systemic blood pressure In dogs chronically fitted with thermostromuhr units on the superior mesenteric artery they found that blood flow is not decreased in running on the treadmill, in fact, in 10 of 17 experiments on 3 dogs it was increased Treadmill speed was 3 m p h and in some experiments the treadmill was inclined about

15° (26 8 percent grade) It is not stated whether the dogs were fasting

Since 1945 (8) when the Bromsulphalein (BSP) extraction method for estimated hepatic blood flow (EHBF) was introduced, numerous measurements have been made of the effect of exercise on EHBF (4,6,7,38,49,51) The original presentation of the method indicated the possible errors in estimating the blood flow in this way Further sources of error, for the anesthetized dog at least, were reported by Andrews, *et al* (1) and Edwards (24) Aside from these technical errors, the method suffers from other defects when it is used to measure the changes produced by exercise These include the necessity for the supine position and the anxiety provoking presence of an indwelling catheter The same difficulties are present when blood flow is estimated by means of oxygen consumption (5) In most of the studies subjects were required to exercise in the fasting state On *a priori* grounds one would expect different results in resting and postprandially In the former state the alimentary tract is resting while in the latter it is active and can compete with active voluntary muscles for blood flow

One study has been made of hepatic blood flow using a modification of the original BSP technic in which the effect of a meal, of exercise, and of both have been determined in human subjects (38) without the use of a catheter Whereas in the fasting, catheterized subject marked decreases of EHBF have been uniformly found (except late riser in, 4) with exercise, in the nonfasting, noncatheterized subject *increases* in blood flow have accompanied meal taking, and exercise has not altered this state Furthermore, even in the fasting, exercised subject no decreases were found Whether this reflects the effect of the nonuse of a catheter or an inadequacy in the method remains to be determined

In summary, on the basis of still too few experiments, it appears that in the fasting human subject the splanchnic area contributes storage blood and in the process suffers a local ischemia The presence of a meal permits this region to compete with skeletal muscles, and as a consequence blood flow remains adequate for the local needs Whether in the meantime a storage function is subserved remains a moot point One final comment must be made in none of the human blood flow studies has the work load been anything like that in the previous motility and secretion studies

THE LIVER

Very few studies have been made of the effect of exercise on the liver According to Bridzius (9), Frerichs (1858) concluded from experiments in man, rabbits, and cats that body movements can reduce the digestive hyperemia in the liver And Ranke (1871), using gall bladder fistulas in rabbits and guinea pigs, had found less bile produced during muscle tetanus

In the previously mentioned work of Donaldson (18,19,20,21,22,23), it was found that while chronic exercise increased salivary gland weight, it

reduced slightly (if at all) the weight of fresh liver Steinhaus, *et al* on dogs found similar changes in swimmers but not in runners (46) It is difficult to account for these paradoxical results

In 1950 Mellinkoff and Machella (39) made the interesting observation that 4 hr/day of treadmill walking at the rate of 200 m/hr in rats (21 experimental, 21 control animals) does not interfere with liver regeneration after 70 percent removal In both experimental and control animals there was 100 percent restoration by the 10th postoperative day

THE SMALL INTESTINE

In the economy of the digestive tract one of the functions of the small intestine is to receive the contents of the stomach as the latter organ automatically doles it out The chyme has further digestive ferments added, its reaction is reduced toward neutrality by alkaline secretions, and the remainers and secretions from pancreas, liver, and the small intestine itself are added Finally there takes place in the small intestine the vast bulk of the absorption of water and nutrients so that only a relatively small fraction (perhaps 5 percent on the average) remains to enter the colon for the final absorption of the last 300–400 ml of water

A very early study of the effect of exercise on the small intestine was made by Cash in 1886 (13) A single dog with a Thiry Vella loop of the jejunum was studied with the bolus method Having the dog run around the room caused a rather marked increase in the rate of propulsion of the bolus through the loop

We have recently studied (47) the effect of acute exercise on the propulsive motility of the small intestine in both rats and dogs The charcoal suspension method was used Neither rats run horizontally at 1 m p h nor dogs at 4 m p h and 10 percent grade showed any difference from control animals not run We have therefore failed to confirm the positive findings of Cash although, of course, we used a different method

Van Liere, *et al* have studied the chronic aspects of exercise on the propulsive motility of the small intestine in rats (48) After a month of running one m p h for two hours daily the motility was measured as in the acute studies In a large series of animals (83 controls, 82 experimentals) a small but statistically significant increase in propulsive motility was seen in the exercised rats

In summary, on the basis of all too few experiments it still remains to be proved whether acute exercise has any effect on the function of the small intestine Furthermore, the improvement in motility brought about by

chronic exercise (in one species) is so slight as to be of questionable practical value

THE LARGE INTESTINE

There is a common feeling among many persons (and the expression of this has crept into the *medical and physiological literature) that exercise* promotes the regularity of the large intestine in physiological terms, the propulsive motility is increased Oddly enough, only two experimental studies of the colon have come to our notice, and these involve acute rather than chronic exercise

Barcroft and Florey in 1929 (3) studied the effect of brief periods of running on the vascular condition of an exteriorized patch of the colon in the chronically operated dog Early pallor on running was seen, but since this also appeared in excitement or fear and did not last even in running, it was suggested that running *per se* had no effect on the colon

The only motility study was made by DeYoung, *et al* in 1931 (17) Nine dogs with chronic cecostomies were used and motility was determined with the balloon technique Brief periods (usually 6 minutes) of treadmill running (5 m p h and 22 percent grade) in the majority of cases caused a marked temporary rise in colonic tone and motility This was usually followed by a prolonged period of subnormal activity The early effect was proved to depend upon extrinsic innervation, and could apparently be inhibited by psychic factors (fear) The later hypomotility seemed to arise from a non nervous mechanism This recalls the later finding of Hammar and Öbrink (28) of a humoral inhibitory agent in the blood of exercised dogs

Obviously much needs yet to be done in the way of research if all the effects of exercise on the colon are to be appreciated It is regrettable that the supposedly chronic effect of exercise lacks an experimental basis The small though positive effects on the rat small intestine may be a straw in the wind

HYGIENE OF THE GASTROINTESTINAL TRACT AND EXERCISE

Finally, it is of interest to pose the question of the hygienic effect of exercise in the light of all the physiological findings Is exercise harmful, beneficial, or of no discernible value to the best functioning of the alimentary tract? We are inclined to go along with Hellebrandt, *et al* (30), who state, "when confronted with the necessity of performing strenuous and exhaustive muscular work the beneficent digestive functions are not in abeyance' And, ' the stomach must have what may be called a large margin of safety —the ability to continue working optimally under conditions which seem

unfavorable to normal functioning" Except that we would substitute the entire digestive tract for "stomach"

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13 CELESTE ULRICH

Stress and Sport

SUMMARY

Whenever the homeostatic balance of the body is upset, the human organism attempts to adjust in such a way that the balance is restored. Until the balance is restored, a state of "stress" exists

[illegible]

is, stress which is sufficiently intense to elicit general homeostatic upset)

The physiological manifestations of stress are found in changes of circulation, respiration, metabolism, temperature, and body chemistry. The psychological manifestations of stress are more difficult to define but they may be measured to some extent by the behavioral patterns of the organism.

Sport is a stressor. It has inherent in its structure a patterning of psychic, social, and physical stressors—all of which must be interpreted as an integrated unit. As such, it is possible that sport can elicit a total stress response from the organism.

Total stress may be studied by analysis of the adrenal cortical secretion and this has been accomplished through eosinophil and ketosteroid measures.

At the present time no qualitative assessment can be placed on the effect of stress on the human organism. "Too much" stress appears to be detrimental, but "too little" may be just as bad. However, the quantitative as

provides a challenge, and in the individual's reaction to sport he may find indications of his pattern of reaction to life itself

The human body attempts to adjust to any agent or situation which threatens to destroy its homeostatic balance Recently the term *stress* has been used by physiologists to describe the total bodily reaction in its effort to maintain equilibrium

Physiological stress resulting from homeostatic upset may be caused by either psychological or physical agents or conditions These operate within an external environment which is physically definable, an internal environment of physiological structure and function, and the social environment which surrounds the occurrence and gives meaning to it

Thus stressors (causes of stress) may be physical, psychic, or social in nature However, the human organism in reacting to the stressor and resolving the stress does not appear to differentiate among the stressors

Stress imposed by sports situations has psychic and physical components and as such is fertile territory for research in the stress field Curiously, this type of situational stressor has not been utilized to any great extent (probably because of the uncontrollable variable of the human factor) so most of the information regarding the relationship of stress and sport has been accumulated through related studies The most relevant studies are those

assumption there is cause to suspect that physical work, as such, may *not* be the *main* and is certainly not the *only* stressor involved in sport Reinterpretation of earlier studies and recent research both indicate that the psychic aspects of sport may indeed be the most powerful stressors operating in the situation

Hence in any study of stress and sport, it is essential that the effect of psychic stressors as well as physical stressors be analyzed in terms of both physiological function and manifest behavioral patterns

Since the individual's physiological function and his overt behavior are related and cyclic in cause effect terms, it is impossible to isolate either phenomenon Theories regarding psychic physical relationships have often involved a study of emotions since the psychic element is usually identified in this way

THEORIES OF PSYCHIC PHYSICAL RELATIONSHIPS

Much of the long search for an understanding of the emotions of man has centered around the concept of adaptation It was early determined

that when emotional stress was experienced, certain changes occurred within the body so as to equip the individual to meet the situation at hand. Hippocrates recognized the importance of bodily secretions during emotion, as did Plato and Aristotle. Chaucer and Aquinas mentioned these phenomena long before the establishment of objective evidence concerning the functioning of the endocrine glands.

The adrenal gland was identified by Eustacius in 1563. However, it was Thomas Addison in the nineteenth century who first called attention to the adrenal glands as the "seats of emotion."

In the late part of the nineteenth century Charles Darwin wrote on the overt features of emotional response in men and animals (14). His formulation of three principles for interpreting emotional manifestations, involved the unity of response which was concerned with 'fight-or-flight' adjustment, antithesis, which observed the opposite postures in an animal about to attack and in one about to meet his master, and useless, excessive behavior found in mild fear which becomes paralyzing panic when the fear is great.

James (34) suggested that a 'felt' emotion is a central summation of sensory impulses from an organ whose activity is disturbed. These sensory impressions might come from the heart, blood vessels, respiratory passages, stomach, intestines or contracting muscles. James thought that there was a central focusing of impressions from these regions, which in turn produced the subjective states of joy, rage, grief, fear, and the remaining range of the named emotions. This concept was unified under the James-Lange theory of emotions.

The "fight or flight" theory regarding the physiology of emotional change was postulated by Walter Cannon in 1915. Cannon (10) developed a broad and integrated physiological picture of emotion. His main concern was with the visceral components involved in the emotional reaction. The essential feature was excitation of the sympathetic division of the autonomic nervous system. The stimulation of this system, Cannon explained, brought about a multitude of glandular, smooth muscle, and metabolic responses which resulted in such homeostatic adjustments as increased heart rate, increased blood pressure, and mobilization of the sugar in the blood. Cannon stressed that the fundamental effect of emotional stimulation is increase in the secretion of epinephrine which liberates the sugar which is then available to furnish energy to meet the emergency situation. Cannon suggested that sensations are central in origin and that they result from an irradiation of impulses to regions of low consciousness, perhaps the thalamus. He suggested that in the floor of the fourth ventricle of the medulla is the reflex center for the liberation of the hormone epinephrine, and it is the effect of this hormone which produces the resulting activity in emotional tension. Cannon did not say that the liberation of epinephrine creates feelings, he merely suggested that once the feelings have been created, the secretion of epinephrine

prepares the body for the results that must take place Cannon believed that in many ways epinephrine was the homeostatic regulator of the body in times of stress The Cannon theory has been generally accepted by the majority of physiologists for a long period of time, although in recent years his explanations of the mechanisms involved have been questioned by some investigators

Rogoff (54) opposed Cannon s theory He stated that reactions in major emotions could be explained as being consequences of activity within the nervous system, chiefly sympathetic rather than secretory He claimed that emotion may be seen in animals with adrenal secretion abolished He believed that the emergency theory of direct relation of the adrenal gland secretion to emotional excitation was untenable because it was based on inadequate experimental investigation

The most recent and encompassing work in the theory of emotional reaction to stressful situations and the physiological concomitants involved has been done by Hans Selye a Canadian physiologist, and his associates (61 62 63 64 65 66 67 68) It is their contention that stress is the state manifested by a specific syndrome which consists of all non specifically induced changes within a biologic system Stress has its own characteristic form but no particular cause (67 423) Selye claims that the body sets up a line of defense against the noxious effects of stressor agents and situations, and that this line of defense resolves itself into what he calls an *adaptation syndrome* either specific or general in nature Selye indicates that the organism utilizes adaptation energy in meeting each stressful situation If the stress is within tolerable limits the mobilized body resources resolve the

is shortened by intermittent periods of intense stress, although temporary rehabilitation of adaptability is undoubtedly possible even in severe stress Selye contends further that there is evidence that normal senility and the precocious aging induced by life under stressful situations, are alike in their manifestations Most of the actions of the adaptive hormones are highly dependent upon conditioning factors

The concept of the general adaptation syndrome raises many questions about the specific nature of many diseases Selye favors the possibility that many diseases may eventually be traced to the effects of nonspecific stress The psychosomatic interpretation of illness seems to rest on this concept

All recent theories concerning the emotions have utilized a physiological frame of reference but the interpretations of the theory have had psychological as well as physiological implications At the present time, Selye s theory of stress seems to provide a flexible and thoughtful concept for extensive exploration If the psychic and physical stressors involved in sport elicit the same qualitative stress response, as Selye suggests, a great deal more study

is indicated to advance the understanding of the psychic physical complex inherent in sport

PHYSIOLOGICAL MECHANISMS INVOLVED IN STRESS

Stress has often been thought of in terms of bodily responses or adjustments to invasion by pathogens and their destruction, of meteorological and climatic crises, of physical forces which operate on man s mass and volume, and of elements which man manipulates for his comfort, delight, and destruction On the other hand, Wolff (84,1059) pointed out that man, constituted as he is, is further vulnerable because he reacts not only to the existence of danger, but to threats and symbols of danger experienced in the past which call forth reactions little different from those of the assault itself Wolff observed that perhaps man s greatest threat of all is his doubt about his ability to live the life of a man

Selye states (64) that stress is produced in the body through multiple pathways He says that the effect of a single stressor is always modified by the variable specific actions of the eliciting agent and by the conditioning factors, the terrain, which is different in every individual These conditioning factors can selectively affect the individual pathways, which accounts for the variable manifestations of what, in essence, is but a single stress response

In spite of the varied interpretations of the body s reaction to specific and nonspecific stressors, there is general agreement as to the results within the organism Harrison (27), Wright (85), Evans (18), Houssay (30), and Thorn and Laidlaw (77) have all agreed that the stress reaction may be generalized There is a circulatory response which usually results in increased heart action, pulse rate, and blood pressure The blood chemistry and formed elements may evidence changes i e, increase in polymorphonuclear leucocytes and a decrease in lymphocytes, eosinophils, hemoglobin, and serum albumin There is an alteration in body temperature steroid metabolism, and a change in electrolyte balance It is possible that *all* of these reactions are not *directly* controlled by the liberation of hormones from the adrenal gland However, the great bulk of scientific information tends to support the belief that in times of emotional stress, the general bodily reaction of adaptation is fostered, accentuated, and abetted by the secretion of the adrenal gland

Endocrine Adaptation to Stress

Working with the Norway rat, Richter (52) found that the adrenal glands were smaller in the domestic animal than in the wild rat He noted that adrenalectomized rats have a smaller replacement need when they are domesticated Selye (68) emphasized that the adrenalectomized animals need much larger than maintenance doses of corticoids in order to withstand

stressors He also stated that it is noteworthy that in the case of chronic exposure even to mild stressors, adrenalectomized animals can maintain themselves in the stage of resistance only for a short time before exhaustion and death supervene

Liddell, Anderson, Kotyuka, and Hartman (43) experimented on the effect of adrenal cortex extract on neurotic sheep and found that the administration of this hormone improved the symptoms of disturbance in the neurotic animals The conditioned reflex was also improved They concluded that there was permissive evidence to support the concept that the adrenal cortex hormone and adrenalin are in direct contrast in action

Weiss and English (80) amplified the extent of the stress reaction by theorizing that stress causes the liberation of toxic metabolites in the tissues These metabolites are thought to set up an alarm reaction ' which is characterized by tachycardia decrease in muscle tone, decrease in bodily temperature, formation of gastric and intestinal ulcers, hemoconcentration, anuria, edema, hypochlorydria, leucopenia followed by leucocytosis, acidosis, and a transitory hyperglycemia followed by a decrease in blood sugar and a discharge of adrenaline from the adrenal medulla If the damage is not too severe, the toxic metabolites stimulate the anterior lobe of the pituitary to discharge adrenocorticotrophic hormone (ACTH), which in turn stimulates the secretion of the adrenal cortical hormones and thereby raises the resistence of the body

Evans (18) agreed with this analysis and further stated that the release of adrenalin in states of stress indirectly stimulates the adrenal cortex via the anterior pituitary He added that direct electrical stimulation to the hypothalamus can release ACTH and so stimulate the adrenal cortex It was his contention that these two mechanisms could explain the accelerated output of ACTH which increases the secretion of the adrenal hormones in states of stress Evans believed that when the level of the adrenal cortical hormones in the blood falls there is stimulation of the hypothalamus by which the anterior pituitary is excited to produce ACTH, which then stimulates the adrenal cortex to produce adrenal cortical hormones until the deficiency is made good Anand, Raghunath, Dua, and Mohindra (2) concurred with Evans in the belief that the dual mechanism of ACTH secretion from the anterior lobe of the pituitary, consisting of a ' nervous" phase mediated through the hypothalamus and a 'metabolic" phase in which the hypothalamus takes no part, is a result of stressor agents Bishop (5) supported the belief that stress can lead to the outpouring of adrenocortical hormones with the intact pituitary giving rise to ACTH secretion He stated that adrenaline itself has no effect on the adrenal cortex but must operate through the pituitary to release ACTH

Sayers (58) warned that the exact nature of the secretion of the adrenal cortex is unknown but that the unitarian concept regards the secretion as fixed in composition but varying in rate Sayers said that under optimal

conditions of environment, the pituitary adrenocortical system is in a relatively quiescent state, while in contrast, it is very active under stress

The histological changes in the adrenal cortex depend on whether the stress is mild or severe, develops quickly or gradually, is short lasting or prolonged

Since it has been experimentally demonstrated that emotional excitation is accompanied by adrenal cortical secretion (16,32 48,51,54 64,77), it would follow that by measuring the amount of adrenal cortical secretion, the quantity of stress caused by the excitation could be calculated However, the adrenal cortex has no duct and this complicates the assessment technique

The study of stress in humans is indirect, being confined to measurements of reactions caused by adrenal cortical secretion Within limits these measurements assess the quantity of the hormone secretion The quantity of the hormone secretion suggests the quantity of stress Thus direct measurements of selected biological phenomena become indirect measurements of stress

The biological phenomena utilized for measurement are always phenomena affected by adrenal cortical secretion Such indices as pulse rate, respiration rate, blood pressure, and temperature have been used However, each of these phenomena is sensitive to many forces and constantly adjusts to keep the body in homeostatic balance The possible sensitivity of these indices to a multitude of uncontrollable forces other than adrenal cortical secretion limits their usefulness in experimentation Therefore physiological phenomena less sensitive to many forces and more sensitive to adrenal cortical secretion are used The increase in ketosteroids in the urine and the decrease of circulating eosinophils in the blood are two such measures which provide more exact information about ACTH secretion

Most of the warnings directed against using the eosinophil count or the ketosteroid count as a stress index are cautions regarding the inadequacy of generalizations based on a single index The precaution concerning generalizations from discrete information must be doubly emphasized in relation to the study of emotional stressors Stress caused by emotion may be dealt with in terms of psychoanalytical theory or neurophysiological theory Each frame of reference has value, but a sound basis for explaining psychiatric interpretations in physiological terms or neurophysiological findings in psychoanalytical terminology has not yet been established Hope for eventual understanding of all qualitative and quantitative phenomena related to emotionally derived stress is held by physiologists and psychologists alike, but such an integrated interpretation must wait on an extension of scientifically supported information in both areas

A number of studies have been carried out utilizing the eosinophil count and the ketosteroid count as an index of stress The studies have been concerned with surgical trauma, emotion, exercise, and various physical conditions

Perhaps the greatest amount of experimentation regarding eosinophil

drop in human subjects has been done in connection with pre and post operative trauma Rouche, Thorn, and Hills (53) found that during anxiety before an operation the fall of eosinophils might be 100 percent They recognized that the initial eosinophil level had little significance, but the change in level following stress induced by anxiety indicates the degree of adrenal function reserve Other experimenters such as Schoen, Strauss and Bay (60) and Gabrilove (23) have concurred with this judgment

The type of emotional stressors being used to cause stress has produced some interesting experimentation Thorn, Jenkins, Laidlaw, Goetz, and Reddy (76) studied the response of numerous individuals to primitive aboriginal rites shown on motion pictures and noted that a decrease of circulating eosinophils (eosinopenia) occurred

Mann and Lehmann (46) tested medical students before the students took their final examinations The researchers found that the level of circulating eosinophils had dropped This led them to speculate that increased emotional tension corresponds with low eosinophil counts Humphreys and Raab (32) also observed that a marked diminution of the eosinophil count was apparent in students who were in a state of emotional tension regarding examinations Dreyfuss and Feldman (16) studied eosinopenia induced by emotional stress of students ready for examinations and concurred with the findings of Humphreys and Raab They further noted that eosinopenia *sometimes persisted for as long as* 24 hours Thorn (77) examined candidates for the Doctor of Philosophy degree immediately after their doctoral examinations and noted a marked increase in the 17 ketosteroid output He believed that anxiety increased adrenal cortical secretion Thus when emotional tension is interpreted by the individual to be an alarming stimulus and hence a stressor, there is a drop in circulating eosinophils and an increase in ketosteroid output

Groften and McGrath (26) studied the adrenal cortical function of long distance fliers They found no consistent relationship between the drop of eosinophils and length of flight, although they observed that the crew member who consistently showed the lowest eosinophil count seemed to be most subject to fatigue Howard, Olney, Frawley, Peterson, Smith, Davis, Guerry and Dibrell (31) using the eosinophil count and the ketosteroid count in an extensive study of the adrenal function in wounded and combat soldiers, found that the adrenal response during combat was extensive and appeared to be related to the individual s subjective interpretation of the situation

In most of the exercise experiments the stressors included other elements in addition to exercise, since it is difficult, if not impossible, to isolate exer*cise from the social and emotional components In an attempt to differen*tiate the influence of exercise and emotional factors upon the drop in the eosinophil count, Reynold, Quigley, Kennard, and Thorn (51) counted eosinophils of coxswains, coaches, and oarsmen before and after a race They found that emotional stress, either of itself or in combination with muscular

activity, represents a maximum stimulus for the stress mechanism, whereas this did not seem true of the muscular activity alone Thorn (77), in a critique of this study, observed that anxiety could induce a fall of eosinophils of the same magnitude as experienced by the crew members, thus indicating that large quanities of adrenal hormone may be liberated during periods of mental and emotional excitation, and the person with well marked anxiety may approach the eosinopenia observed in patients with Cushing s disease He believed that hormones are not utilized in anxiety unless physical activity also occurs In another critique of the oarsmen study, Thorn, Jenkins, Laidlaw, Goetz, and Reddy (76) concluded that the decrease in the eosinophil count of the coxswain, who did no rowing, indicates that emotion is more significant than motion in producing stress This hypothesis may be especially important to the researcher studying stress and sport

The concept that the psychological components in a stressor situation are related to stress to a far greater degree than the components involving physical activity was supported by Ulrich (78) in an experiment investigating college women for stress elicited by a variety of competitive situations including physical activity and psychological interpretations which are a normal part of the college educational experience She also concluded that stress is related to identifiable differences in past experiences which are relevant to the situation

Wake, Graham, and McGrath (79) did eosinophil counts on men who exercised as compared with men who rested They found that the counts were significantly lower on the days of exercise They concluded that exercise in itself causes activation of the adrenal cortex

Stress always involves a physiological reaction with characteristic form There is a circulation, temperature, metabolism, and blood chemistry change *and this change appears to be triggered by endocrine fluctuation* The adrenal cortex is largely responsible for effecting the form of the stress response

Circulatory Changes in Stress

Much of the physiological research regarding emotional stress has centered around various aspects of the circulatory responses The cardiorespiratory systems are quickly affected by stress and the response can be measured with relative ease

Wolf (83) stated that the functions of the mechanical design of the heart pump valves, fuel for work, composition of the coronary blood and caliber of the vessels, blood volume, extent of the peripheral vascular bed, resistance of the peripheral vascular bed, blood viscosity, stroke volume, heart rate, blood pressure, and heart rhythm may be significantly altered during an in*dividual s attempts to adapt to people and events in his environment* He noted that blood viscosity increased as much as 20 percent in relation to stressful situations

Selye (62) found that blood clotting time decreases during the alarm re-

action phase of stress while the platelet count rises, fibrin formation is accelerated, and the red blood cell and hemocrit values are increased He also found a pronounced increase in total white blood count and observed that this nonspecific leucocytosis may be preceded by a decrease in the number of circulating eosinophils

The action potential of rats was recorded by Beebe Center and Stevens (3) who used gunshots and the appearance of dogs as emotional stimuli The extent of the heart rise in the rats was about 30 beats per minute The sudden presentation of the dog increased the heart beat 8 percent These data suggested to the researchers that reactions in emotion are due to activity of the sympathetic system

Altschule (1) indicated that emotion may increase cardiac output by two thirds and said that in emotionally disturbed subjects exercise of a mild nature causes a greater rise in pulse rate than in the same subject when he is not upset Altschule s conclusions were supported by Whitehorn, Kaufman, and Thomas (82) who stated that cardiac acceleration as a rule is found in emotional states They studied neurotic and emotionally disturbed individuals and found a significant cardiac acceleration However, the researchers emphasized that there was no physiological pattern of activity characteristic of specific emotions even if such entities exist

There seems to be sufficient accumulated evidence to support the belief that the normal heart cannot be strained by physical exertion This excludes the heart of doubtful integrity or the diseased heart Gavey (24), in discussing this concept offered the provocative statement that emotion is more dangerous to the heart than exercise since emotion cannot be easily controlled However, he commented that life is for living and that risks and their emotional concomitants are a part of living which should not be avoided merely to protect the heart from exertion

Hickham, Cargill, and Golden (29) stated that emotional disturbances may have a profound effect on circulation, causing changes in heart rate, cardiac output, blood pressure, tone of the peripheral vessels, and electrocardiographic records They cautioned that the interpretation of data relating anxiety to circulatory changes is handicapped by the absence of reliable objective means of measuring the degree of anxiety in individual subjects, and they concluded that variability of the cardiac system is qualitative as well as quantitative

In an effort to describe certain qualitative results of stress on the cardiovascular system, experimentation was done by Schneider and Zangari (59) They stated that when emotional conflicts were associated with stressor response, significant changes occur in the blood which are similar to the changes following muscular exercise During anxiety, fear, and tension, clotting time decreased, relative viscosity increased, and the blood pressure was elevated They postulated that such a circulatory syndrome may eventually prove detrimental by favoring intravascular thrombosis

RESPIRATORY ADAPTATION TO STRESS

The evidence concerning respiratory adaptation to stress is far from conclusive The variability of the respiratory mechanism makes its response difficult to measure Usually the demand for more oxygen is met by ventilating a larger volume, increasing the rate of oxygen absorption in relation to ventilation, increasing the cardiac output, and finally increasing the rate of absorption in relation to blood flow

Bruce, Lovejoy, Pearson, Yu, and Velasquez (6) agreed with Ruosteenoja (55), McDowell, *et al* (7), and Ulrich (78) that the stress of exercise not only makes marked demands upon the respiratory system but also there was some indication that this demand was further increased in mild exercise during emotional excitation

OTHER ADAPTATIONS TO STRESS

Marston (47) hypothesized that both feeling and emotion are objectively a particular kind of energy generated at the synapses of motor integration centers in the brain He ascribed these centers a position in or near the hypothalamus The energy, which he called *motorpsychonic energy* is based upon the integration of two classes of impulses tonic ones which are self regulating impulses originating from the muscles and glands, and phasic impulses originating from environmental influences Marston said that feeling depends upon the nature of the interaction

already present condition with the intensity of the disturbance being dependent upon the intensity of the stress stimulus, the personality of the individual, and the threshold of discomfort

A significant concordance among four distinct muscle groups, which suggested that the body musculature as a whole more forcefully contracts in patients who are anxious, was pointed out by Sainsbury and Gibson (57) They suggested that feelings of irritability and restlessness during stress may be the consequence of massive bombardment of the central nervous system by proprioceptive stimuli arising from the widespread contraction of the voluntary muscles

PSYCHOLOGICAL COMPONENTS INVOLVED IN STRESS

When any stressor is brought into focus via a psychological interpretation, the general physiological adaptation of the body to that stressor is similar to the body s adaptation to a stressor of physical nature Thus alarming stimuli of neurogenic or psychogenic nature can be particularly potent

activators of the adrenocorticotrophic hormone secretions and produce rapid and intense alarm reactions Emotional sweat cannot be differentiated from exercise sweat and this concept becomes increasingly important in sport

Since psychic stressors are usually a result of emotional interpretation it is important to attempt to discover more about the emotions and their interpretation

Many psychologists agree with Podolsky (50) that emotional stress is the product of anxiety In reviewing the effect of stress upon man, Podolsky expressed the view that anxiety came into man s awareness when he acquired a conception of time as the carrier of future events Since man is finite in a limited time the tragic character of anxiety evolves Man is being constantly oriented toward his own possibilities Thus anxiety exists essentially as a time element and may be expected to arise whenever the individual

as its shadow In support of this construct Sackler, Sackler, Sackler, and van Ophuijsen (56) stated that psychic adaptation is more an intellectual and emotional process than a matter of physical prowess This idea may be very relevant in sport especially when athletic competition is a major source of psychic stress

In his psychiatric analysis of stress MacCalman (44) indicated that all living organisms have a threshold beyond which they will break down in response to stress He emphasized that previous emotional upsets can so sensitize the individual that he is upset by small amounts of stress, whereas the individual who possesses considerable psychological stability can withstand severe stress for long periods Lazarus Deese and Osler (42) stated that stress caused by psychic upset may be thought of as an intervening variable a secondary concept built upon the relationship between the primary concept motivation and the situation in which motivated behavior appears They stated that the psychologist has no way of determining the psychological condition which corresponds to homeostasis Psychological stress may be induced by such things as failure, working conditions or, the task itself The cause is seldom clear cut

tions in the realm of physiological stress as did Cohen and Rubinstein

(13) In addition, they indicated that the physiological changes are not cause effect structured, and stated that the physiological manifestations represent only a portion of the total response

Hunt (33) postulated emotional tension to be a reflection of the biological forces which motivate the organism He said that if biological tensions were not adequately relieved, they accumulate and affect the adrenal cortex to produce disturbances of thought and behavior mostly via the autonomic nervous system which in turn affects the physiological system and produces stress symptoms

Cleghorn (12) pointed out that a trifle to one individual might well be consternation to another He noted that in our society adaptation is necessary but warned against thinking about the body as an animated adrenal cortex

It is apparent that stressors affect behavior, but it also appears that the overt effects of any stressor are related to the subjective state of the individual to such an extent that the subjective state of the individual may largely determine the stressfulness of the situation

Recent studies in behavior may generally be classified into two groups first those which isolate the mechanisms which are operative in adaptation to stress and second, those which permit prediction of behavior under conditions of stress

The behavior of the organism under controlled stress provides an index for behavioral prediction Much of the earlier work done in the field of behavior during stress was done with neurotic personalities, but more recently there has been a trend toward experimentation with normal persons

Kohn (39) had subjects study pictures under experimental conditions of anticipated electrical shock He found that perception was least effective when the pictures were studied in an environment where shock is anticipated and most effective when studied in an environment involving low emotional intensity He concluded that severe emotional stress reduces the scope of a complex perceptual activity and the disruptive influence of emotional tension is localized in the irrelevant or less important aspects of the perceptual task rather than the relevant items This concept was essentially substantiated by Johnson (35,36,37) in his work with athletes and emotional stress

That anxiety modifies intellectual functioning and imagination activity was reported by Hartogs (28) There seemed to be some indication that high anxiety level affected visuomotor control Osler, *et al* (42) carried on an experiment on intellectual performance as it is related to psychological stressors She administered tests to get a base score and then re administered the test introducing the psychological aspects of fear and failure She found that failure as a stimulus depressed performance, but fear did not However, failure was associated with the task at hand while fear was associated with a general social pattern

The effect of failure as a stressor upon skilled performance was studied by

Lazarus and Eriksen (42) They found that a significant increase in inter individual variability in test performance occurred in the stress group The increased speed with which the task is done often compensates for the number of errors made under stress Of interest was the fact that the students with a high grade point average got better under stress while those with a poorer average did more poorly and were much more variable

Feffer and Phillips (20) in their study of social attainment and performance while subjects were under stress observed that social inadequacy is related to inability to cope with stressful situations Schizophrenic individuals have poor adaptation to stressful situations Those individuals who are of high social attainment will perform more adequately under conditions of experimental stress

Using a specific motivational pattern as a stressor Burke and Ulrich (8) found that greater work output is elicited by the use of motivation than is elicited when motivation is omitted and that when motivation indicating success is employed the gross mechanical efficiency of the body is greater than when neutral motivational patterns or patterns indicating failure are employed

Berkeley (4) utilizing the technique of urine analysis of the 17 ketosteroids response studied stress as measured by a level-of aspiration test and the Rotter Aspiration Board He found that greater discrepancies between aspiration and achievement in the level of aspiration setting are accompanied by increased activity of the adrenal cortex as indicated by the ketosteroid increase

It is apparent that psychic stressors are able to elicit a stress response from man This stress response is not different in form from that of any stress response and although it may be termed psychological in nature it is mani

with identical physical stressors

IMPLICATION OF STRESS FOR SPORT

Sport combines physical psychic and social stressors in an integrated pattern which requires the total response of the organism The physical stress which is caused by exercise and is usually measured in foot pounds of work has been studied extensively Although much remains to be known about the body s reaction to exercise there is a wealth of information already available On the other hand little research has been done on the psychic

component of the sport stressor and there seems to be indication that this component may well be a crucial key to the future understanding of sport The answer to why two individuals of comparable structure and function *cannot perform comparably may possibly in many instances be found* through analysis of the effects of their psychic and social climate

We know that the stress response includes circulatory changes, cardiorespiratory changes, metabolic changes, temperature changes, and body chemistry changes The changes occur as a result of any homeostatic upset instigated by a stressor, evidently regardless of the nature of the stressor It appears that the body does not attempt to separate kinds of stressors but reacts to them in their totality This does not mean to indicate that the body does not have a specific way of dealing with focal stress Obviously, the body reacts to a burn differently than it reacts to a thrombus, yet the general adaptation is essentially the same It is much more difficult to differentiate in the body's reaction to emotional stressors such as love, hate, fear, and anxiety Here, the physiological reaction of emotional stress appears to be physiologically identical to the reaction induced by physical stress and it is in the behavioral pattern that we find the key to understanding the adaptation

Since in sport we are interested in the behavioral pattern as much as the physiological pattern, it is apparent that both must be studied and in relation to one another rather than separate entities

Selye's theory of stress seems to provide a reasonable and meaningful frame of reference for the researcher in sports stress His claim that stress is

supports and fits into the theory This theory of stress does minimize "cause effect physiology" but it offers in its stead a more encompassing structure which may in time bring the psychological aspects of the organism's reaction into sharper focus

It seems apparent at this time that the study of stress is best accomplished through some endocrinological means This especially indicates the adrenal cortex, and both eosinophil and ketosteroid count have been used as measures of adrenal cortical secretion

There is one important caution to be observed when humans are used as stress studies It is essential that base conditions be established before the stressor is imposed and then the *difference* in the changes between base and stress conditions is the statistic of interest The wide difference between individuals' base conditions makes a comparison *between* individuals' stress conditions meaningless The interest is *within* the individual rather than *between* individuals

At the present time no value judgment can be passed upon the effect of stress on the human organism There is some evidence to indicate that too

much stress over a long period of time is detrimental to the body, but the quantitative definition of "too much" or "too great" is relative to each individual

It may be hoped, therefore, that sport may be used as a composite stressor to test the body's reaction to stress Thus the game of life is set, and sport provides a testing opportunity—a testing ground larger than a playing field and just a little smaller than life itself

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LAURENCE G WESSON, JR

Kidney Function in Exercise[1]

SUMMARY

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general body adjustments designed to cut down blood flow to organs which can temporarily spare some blood in order to make the maximum volume available to the muscles Renal blood flow decreases in proportion to the severity of the exercise and may decrease by more than half Filtration rate decreases very little when changes in renal blood flow are small but decreases in equal ratio to renal blood flow when blood flow changes are large Urea, creatinine and phosphate excretion are decreased moderately due to decreased glomerular filtration, while sodium chloride excretion decreases marke [illegible]

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defined are also important Urine flow decreases by variable amounts because of decreased glomerular filtration and of increased antidiuretic hormone production

After exercise renal blood flow and filtration rate return to the pre-exercise level—in about an hour after moderately severe exercise Simultaneously, urea, creatinine, and sodium chloride excretion return to or close to normal Urine flow rises if the individual is still under a water load There may be a transient proteinuria Potassium excretion returns to the pre exercise level after mild exercise but studies in severe exercise have not been reported Phosphate, titratable acid, and ammonium excretion rise abruptly to levels several times the pre exercise rate In the case of phosphate, the

[1] Appreciation is expressed to Homer W Smith for his critical reading of this chapter

postexercise rise probably results from rising filtration rate together with an effect of acidosis which depresses tubular re absorptive capacity for phos phate The rise in titratable acid and ammonium production is attributable to a combination of the acidotic stimulus and increased phosphate excretion The increased excretion rates of these three substances are not sustained, however, and they have returned to the pre exercise values within an hour after exercise

EXPERIMENTAL STUDIES

Renal Plasma Flow

Effective renal plasma flow (ERPF) is regularly decreased during and for periods as long as an hour after exercise The magnitude of the decrease rate of decrease, and rate of recovery appear to be correlated with the dura tion and degree of exhaustion or taxation of the individual In severe ex hausting exercise, ERPF may decrease to ⅓ the resting rate It is technically impossible by the usual means to measure renal function accurately during severe exercise of no more than a few minutes duration but ERPF measured immediately after such exercise is found to be low It does not go lower but returns, apparently within one to two hours to the pre exercise control value

Changes in ERPF during exercise in persons with heart disease do not

which the arterioles are caused to constrict is unknown Definitive studies to evaluate the role of the renal nerves have not been made

Barclay *et al* (2) measured ERPF (diodone clearance) before, imme diately after and about an hour after brief, severe exercise in nine, 17–20-year old students The subjects were water loaded to promote an increase in urine flow and were recumbent during the two 15–20-minute pre exercise and three to four postexercise periods Exercise consisted in a ¼ mile run at top speed ERPF averaged 736 before, 447 immediately after, and 579 ml/min in the last one or two clearance periods White and Rolf (29) measured the effects of moderately exhausting exercise, consisting of running 4 to 7 miles per hour for 10 to 15 minutes, in 6 experiments on 4 subjects One subject was middle aged, the others in their 20's With the subjects water loaded, one or two periods were obtained before, one during, and two

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After exercise, renal blood flow and filtration rate return to the pre-exercise level—in about an hour after moderately severe exercise Simultaneously, urea, creatinine, and sodium chloride excretion return to or close to normal Urine flow rises if the individual is still under a water load There may be a transient proteinuria Potassium excretion returns to the pre-exercise level after mild exercise but studies in severe exercise have not been reported Phosphate, titratable acid, and ammonium excretion rise abruptly to levels several times the pre-exercise rate In the case of phosphate, the

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further analysis The most detailed studies are those of Chapman, *et al.* (4). Exercise consisted in walking about 35 minutes on a treadmill at 3 miles per hour (m p h) at no grade, at 3 m p h on a 5 percent grade, and at 3 5 m p h on a 10 percent grade The subjects (9 students) were water loaded and 2 pre and 2 or 3 postexercise periods were measured with the subjects recumbent Two periods were obtained during the exercise ERPF decreased almost linearly during the two exercise periods, the rate of decrease increasing with work load As compared with the pre exercise level, ERPF decreased during zero grade walking by 6 percent in the first period and by 15 percent in the second, by 17 and 27 percent during 5 percent grade walking and by 25 and 35 percent during 10 percent grade walking Forty minutes following the exercise, ERPF had returned nearly to pre exercise levels for all grades of exercise 97, 87, and 94 percent respectively Gibbons, *et al* (10), following the same experimental protocol as Chapman, *et al* measured the effects of walking 3 m p h on a treadmill at 5 and 10 percent grades on 12 patients with minimal cardiac impairment due to aortic in sufficiency. The mean pre exercise ERPF, 487 ml /min , decreased 21 7 and 26 1 percent respectively during the second exercise period at the two work levels Freeman, *et al* (9), extending the studies of Merrill and Cargill, reported the effects of exercise in the supine position on ERPF (PAH clear ance) in 15 normals and 11 patients with heart disease The cardiacs were divided into 5 "compensated" (edema free and ambulatory) and 6 'severe" (bedridden and edematous) patients Exercise consisted in working "as vigorously as possible to the point of exhaustion' by pushing in the supine position foot pedals against a 10-pound resistance The work lasted about 8 4 minutes in the normals and 8 and 6 9 minutes in the "compensated" and "severe" groups respectively with rest periods as desired A single exercise period was preceded by 2 control and followed by 2 recovery periods, all of about 15 minutes' duration All subjects were hydrated In the normals, ERPF decreased during exercise to 91 4 percent of the mean control of 540 ml /min and recovered to 93 5 and 95 7 percent of the control in the first and second recovery periods, respectively Comparable figures for the "com pensated" cardiacs are 92 percent of a 360 ml /min control and 78 7 and 83 5 percent during the recovery periods For the "severe" cardiacs, the fig ures are 38 4 percent, and, during the recovery periods, 106 5 and 103 1 percent of a 286 ml /min control Both the decrease during exercise and the rate of recovery following exercise in the "severe" group are probably too great, a reciprocal error attributable to dead space effects and not easily corrected

Glomerular Filtration Rate

Glomerular filtration rate (GFR) decreases relatively less than ERPF during exercise As a consequence, filtration fraction (FF) rises GFR is regularly decreased to values ½ to ⅔ normal during and immediately after

severe exercise and generally moves closely parallel to LRPF when changes in the latter are large

The mechanism by which a particular value of GFR is attained appears to reflect the relative effectiveness of efferent arteriolar constriction in sustaining filtration pressure When the decrease in LRPF is small, constriction of the efferent arterioles is capable of sustaining GFR near the control level so that FF rises When the decrease in LRPF is very large, excessive concentration of plasma proteins in the process of filtration probably causes a lowering of filtration pressure with a consequent lowering of GFR in spite of intense efferent arteriolar constriction and FF does not continue to rise

The earliest estimates of glomerular function were based on creatinine excretion and creatinine clearance and can be considered as no more than approximation methods Later studies using inulin, are considered more reliable, although the large changes in urine flow in exercise (see below) throw doubt on the quantitative accuracy of all methods of measurement

Wilson, *et al* (30) measured in three subjects the effects on creatinine excretion of running up and down a flight of stairs for one to three minutes The subjects were water loaded prior to the exercise and urine was collected at 10-minute intervals Comparing the averages of 2 immediately postexercise periods with 3 pre-exercise periods creatinine excretion was unchanged increased 2 percent, and decreased 13 percent respectively Cowan and Rehberg (5) measured exogenous creatinine clearance on 2 subjects before and during heavy exertion for 12 to 60 minutes on a bicycle ergometer Work at the rate of 720 to 1080 kg meters/min was not associated with a significant change in clearance Creatinine clearance progressively decreased at work loads above 1080, decreasing to 37 percent of the control at 1620 kg meters/min in the one subject able to perform this work Kattus, *et al* (16) were unable to detect any significant change in endogenous creatinine clearance in 3 subjects during mild exercise consisting of walking on a horizontal treadmill at 3 m p h for 25 to 50 minutes Eggleton (8) measured creatinine excretion before and at intervals after brief severe exercise consisting of a 40-to-60-second sprint in students Average creatinine excretion decreased rou [illegible]
18 percent in [illegible]
Excretion rate [illegible]
or nearly to the control rate 60 minutes following the exercise

The experimental protocols of the following authors have been described briefly in the preceding section on renal plasma flow Barclay, *et al* (2) reported that the average inulin clearance of 9 students was 116 before, 62 immediately after, and 100 ml /min an hour after short severe exercise Corresponding FF were 17, 14, and 17 percent Barclay, *et al* are the only investigators to report a decrease in FF during exercise White and Rolf (29) reported the average inulin clearance per 1 73 M^2 of 4 subjects was 105 before, 48 during, 84 in the first period after, and 89 ml /min in the

next two periods after moderately severe exercise Corresponding FF are 17, 20, 20, and 18 percent Merrill and Cargill (18) report an average inulin clearance of 130 before, 106 during, and 127 ml/min after stair climbing in 6 subjects with corresponding FF of 24, 27 3, and 25 percent Average inulin clearance of 8 subjects exercising with foot pedals was 105, 91, and 104 ml/min with corresponding FF of 26 3 27, and 28 percent In two or three subjects of each group however, GFR was not significantly decreased Average inulin clearance of 4 cardiacs was 116 before, 77, during and 121 ml/min after stair-climbing, with corresponding FF of 26, 28 3, and 29 percent Freeman, *et al* (9), extending the studies of Merrill and Cargill, report that mean GFR of 15 normal adults decreased from 107 2 in control periods to 105 1 ml/min during exercise in the supine position by pushing foot pedals The change is not statistically significant but this cannot be construed to signify that no decrease occurred Mean FF increased from 19 8 in the control periods to 21 6 during exercise and 21 0 in the average of 2 recovery periods Mean GFR of 5 'compensated' cardiacs was 97 in the controls, 93 2 during exercise, and 86 0 in the recovery periods with corresponding FF of 27 0, 28 2 and 29 0 percent In 6 'severe cardiacs, GFR was 97, 41 7, and 97 7 ml/min with FF of 33, 35, and 35 7 percent before during, and after exercise, respectively The excessively low value of GFR during and the high value following exercise are attributable to dead space effects as indicated above with respect to ERPF studies Aas and Blegen (1) report an average inulin clearance of 155 before and 145 ml/min during moderately severe exercise in a young man FF increased from 17 to 24 5 In 2 young women average inulin clearance was 179 before and 68 ml/min during exhausting exercise FF increased from 22 5 to 28 9 percent Inulin clearance was unchanged in one of 2 cardiac patients and decreased from 85 to 71 ml/min during exercise in the second cardiac FF increased from 22 3 to 25 4 percent and from 16 7 to 26 4 percent in the 2 cardiac patients respectively Judson, *et al* (14) report without data a decrease in GFR in all of 20 cardiac patients during mild exercise Sinclair Smith, *et al* (22) report that inulin clearance (single injection technique) decreased significantly in 3 or 4 out of 5 cardiacs subjected to mild exercise but their data are not susceptible to further analysis Werko, *et al* (26) measured inulin clearance in three groups of cardiac patients with mild, moderately severe and severe degrees of limitation of function before and during mild exercise Average inulin clearance decreased 2 5 in the mild, 4 0 in the moderately severe, and 8 ml/min in the severe group during the exercise

Urea and Total Nitrogen Excretion

Urea excretion regularly decreases during and immediately following moderately severe to severe exercise When plasma urea is constant, as during the short periods represented by exercise and an hour postexercise recovery period, urea excretion varies directly but in a complex way with both GFR

and urine flow (26) the smaller the urine flow (greater urinary urea concentration), the greater the losses of filtered urea back into the blood stream Consequently, changes in urea excretion show correlations with both these other terms and are difficult to interpret

Total urinary nitrogen is composed mostly of urea and creatinine, urea alone accounting for about 85 percent and urea plus creatinine accounting for over 90 percent of the total nitrogen Consequently, changes in total nitrogen excretion are usually due to changes in these two compounds

Several authors have reported decreases in either urea or total nitrogen excretion during and immediately after exercise in normal individuals (5 6 9 17) Duncan (6) reported small decreases in urea excretion in 4 experiments on 2 normals during mild exercise which consisted of walking 4 m p h for 14 minutes Data are presented for only one experiment, however In 6 moderately severely limited cardiacs who walked slower for the same time, urea excretion decreased 36 percent in the group average Urine flow and sodium excretion also decreased markedly but by different percentages

Urine Flow

Rate of urine flow usually decreases during exercise but the magnitude, duration and rate of decrease are not accurately predictable Since subjects have been water loaded and are undergoing a water diuresis when they begin exercise the major cause of the decrease is probably due to liberation of antidiuretic hormone (ADH) Unpredictability of urine flow change is probably due to variation in response of the posterior pituitary to a given degree of stress emotional components irrespective of the severity of the exercise and variations in pre exercise degree of hydration In addition, decreases in GFR result in less sodium chloride, water, and total urinary solids reaching the distal segment of the nephron so that less water is available to form a water diuresis If the subject is not water loaded, less solids are available to limit the action of the concentrating mechanism The precise contributions of the two factors (GFR change and ADH production) during exercise have never been evaluated experimentally The decrease in urine flow is not directly proportional to the intensity of the exercise During mild exercise no change in flow is evident When a level of exercise is reached which is definitely strenuous urine flow generally decreases rapidly to remain low until a few minutes after the exercise when it rapidly returns to or close to the pre-exercise level

he

warm tea A tea diuresis differs slightly from a pure water diuresis in that

the contained xanthine derivative, caffeine, appears to inhibit the posterior pituitary and to increase renal blood flow and filtration rate (23) The authors used themselves as subjects With gradually increasing running speed, urine flow remained high at 5 to 10 ml/min until speed was about 5 m p h at which point it dropped rapidly to levels less than 2 ml/min The drop in urine flow appears first several minutes after the start of a 6-to 8 m p h run, and the postexercise rebound in flow occurred about 8 minutes after stopping the exercise The effects of exercise on flow were not significantly affected by air temperature, amount of clothing or amount of sweating and could not be duplicated by hot baths Barclay, *et al* (3) noted an apparent diurnal variation in response Diuresis from drinking 1 8 liters of water was significantly inhibited by a ¼ mile run during the morning in 29 of 30 students Similar experiments performed in the afternoon resulted in urine flow inhibition in only 9 of 20 students Eggleton (8) also emphasized the considerable individual variability in response of urine flow to exercise in students Exercise consisted of a 40-to 60-second sprint Urine flow usually was decreased following exercise but the decrease was frequently gradual and the rebound did not appear until about 20 minutes afterward There was no evident correlation between urine flow and excretion of chloride or creatinine The pattern of the individual responses of urine flow to exercise was the same whether a pint of water or a pint of tea had been taken to promote flow The 2 diuretic agents differed in that the tea diuresis averaged 50 per cent greater than the water diuresis throughout the experiments

Sodium, Chloride, and Potassium Excretion

A rapid and profound decrease in sodium chloride excretion occurs almost invariably during and after moderately severe and severe exercise The decreased excretion returns only gradually, over an hour or more, to the control levels The decrease in glomerular filtration rate, noted above, is a sufficient cause of the decrease in sodium chloride excretion, while no changes in adrenocortical function or blood composition have yet been recognized which can account for the pattern or which contribute significantly to the changes in salt excretion which have been observed

Experimental studies on potassium excretion are meager In mild exercise potassium excretion either does not change or decreases slightly with rapid recovery afterward A reasonable explanation of the decreases in potassium excretion which have been reported is a diminished supply of sodium ions to the potassium secreting segment of the nephron It may be predicted, however, that effects attributable to changes in respiration and in blood potassium and acidity will be observed in relation to more strenuous exercise

MacKeith, *et al* (17) reported that chloride excretion decreased during three or four experiments in which it was measured but published no data Wilson, *et al* (30) measured chloride excretion at 10-minute intervals in 3 experiments before and after running up and down a flight of stairs for

1 to 3 minutes Mean chloride excretion rate decreased from 0.117 to 0.024 mm/min during the first 20 minutes postexercise and then began to rise slowly Havard (12), Eggleton (8) and Barclay, *et al* (3) report that chloride excretion decreases to extremely low levels during and following brief, hard running by students The mean decrease in excretion in Eggleton's experiments was 0.20 mm/min It must be emphasized, however, in this and following studies that both absolute and percentage changes in sodium and chloride excretion have little significance when the control excretion rate is not known a datum which often is not published Chloride excretion may continue to decrease during the immediate postexercise period (8,11) but usually begins to rise after 20 to 30 minutes When subjects have been water loaded prior to exercise chloride excretion has failed to attain the control values 90 minutes after exercise With tea as the diuretic, however, chloride excretion has generally returned to the control level 60 minutes after exercise (8) Kattus, *et al* (16) and Sinclair Smith, *et al* (22) reported the effects of mild exercise on normal subjects and cardiacs Exercise consisted for the normals of walking 3 m p h for 30 minutes on a level treadmill and for cardiacs of slow or intermittent walking for 25 to 40 minutes Both sodium and chloride excretion decreased in all experiments, the sodium relatively more than the chloride probably because of roles of sodium in potassium and acid excretion Sodium excretion in the experiments of Kattus, *et al* (normals) decreased by about 0.10 mm/min and return to the control level 20 to 40 minutes after the exercise Cardiacs responded in a roughly similar manner but recovery was more irregular Werko, *et al* (26) reported that sodium excretion decreased on the average 0.04, 0.05 and 0.05 mm/min

that the control rate of sodium excretion is lower so that the percentage change is frequently greater with the more severely incapacitated individuals Judson, *et al* (14) state that sodium excretion decreased during mild exercise (straight leg raising in the supine position) in only half of 20 cardiac patients tested and not at all in normal subjects Duncan (6) compared the effects of a brisk walk for 14 minutes on sodium excretion in normals and moderately severely limited cardiacs The normals walked 4 m p h and the cardiacs for whom this pace was too difficult, somewhat slower Sodium excretion decreased 'slightly' in the normals, for whom full data are not reported, and profoundly in the cardiacs The magnitudes of the decreases in excretion are related to the control excretion rates Sodium excretion by one patient, for example, decreased from 0.300 before to 0.003 mm/min

in 15 normals, 5 "compensated" cardiacs, and 6 'severe' cardiacs All subjects

were supine throughout the experiments. In the normals, sodium excretion decreased slightly, from an average of 0.164 in the controls to 0.148 mm./min. during the exercise. The small decrease is consistent with the small and uncertain decrease in GFR. No change in excretion (0.147 mm./min.) was observed in the 2 recovery periods lasting 30 minutes. Mean sodium excretion rate of the compensated cardiacs was 0.148, 0.124 and 0.143 and of the severe cardiacs 0.124, 0.060, and 0.095 mm./min. before, during, and after the exercise, respectively.

Kattus, *et al.* (14) and Sinclair-Smith *et al.* (22) described the effects of mild exercise on potassium excretion in normal and cardiac subjects (see preceding paragraph). In about half of their experiments potassium excretion did not change significantly. In other experiments, potassium excretion decreased by small and variable amounts. The average change was a 15 per cent decrease, and recovery usually occurred within 30 minutes following the exercise. No difference between normals and cardiacs was evident.

Acid, Ammonium, and Phosphate Excretion

Urinary pH regularly decreases to quite acid levels during and following exercise. The decrease usually begins immediately after onset of exercise and frequently before changes in urine flow can be detected. Since urine can seldom become more acid than approximately pH 4.8, the extent of the pH change is largely determined by the pre-exercise value. After exercise, pH returns gradually to the control levels. Although the causes of the pH decrease can probably be enumerated, the importance of each is unknown. Among the causes may be listed: decreasing urine flow which may act in part by concentrating urinary acids; decreased filtration of sodium bicarbonate because of lowering of both filtration rate and plasma bicarbonate concentration; and increased stimulus to acid production from lowering of

Titratable acidity, measured by the amount of alkali needed to titrate the urine to the pH of blood, usually exhibits few significant changes during exercise, but afterwards rises steeply to high levels and reaches a maximum 20 to 40 minutes afterward. Although an acid pH is necessary for significant titratable acid excretion, the two terms do not necessarily move parallel. Titratable acidity is determined by a combination of tubular secretory drive, amount of alkali reaching the secretory portions of the nephron, and in particular by the amount of buffers and exchangeable sodium ions reaching the acid secretory elements. The most important buffer is disodium phosphate and changes in buffer excretion are, for practical purposes, changes in phosphate excretion, the urinary excretion rate of which is determined by the difference between filtered load and tubular re-absorption of phosphates. The irregular changes in titratable acidity during exercise are probably due

to opposing effects of increased stimulus to acid secretion and decreased rate of phosphate excretion, while the rise in acidity after exercise is caused by persisting tubular secretory drive combined with increasing phosphate excretion The rise in phosphate excretion, which may considerably exceed the control values, is attributable to a return of glomerular filtration rate to normal and to a decrease in tubular re absorption of phosphate during acidosis (20) There is no evidence that the postexercise increase in phosphate excretion results from a rise in blood phosphate although this may be a factor in random experiments Ammonia excretion moves parallel with titratable acidity, rising to a peak about 30 minutes postexercise The factors determining ammonium excretion (secretory stimulus combined with availability of sodium or hydrogen ions for exchange) are largely the same as those determining titratable acid excretion

The pH changes in urine during and after exercise have been described by a number of workers (2 3 7 8 17 25) during and following moderately severe to severe exercise Eggleton (7) observed a mean decrease of 1 5 pH units immediately after exercise but in her experiments as in those of others, pre exercise pH was increased as a result of water diuresis (2) Changes in pH without diuretics have not been reported MacKeith, *et al* (17) reported that titratable acidity varied irregularly during exercise but usually decreased slightly After exercise, acidity increased rapidly, reaching a peak excretion rate as high as 0 1 mm /min about 40 minutes afterward They also stated, but without reporting the data, that ammonia tended to fall during the early dyspneic phase of exercise and to rise somewhat upon attainment of second wind and thereafter to parallel acid excretion Eggleton (8) measured titratable acidity ammonia and phosphate excretion before and after a 40-to-60-second sprint in 12 students Urine flow was promoted in some by drinking water and in others by drinking tea Titratable acidity increased by 0 04 and ammonia by 0 05 mm /min Phosphate excretion increased between 0 023 and 0 046 mm /min The maximum excretion rates of all 3 substances occurred 30 minutes after the exercise The observations of Havard (12) and of Wilson, *et al* (30) are qualitatively similar to those of Eggleton Havard reported that phosphate and ammonia excretion diminished during brief, severe exercise but afterward approximately doubled the pre exercise rate Wilson, et al reported that following 1 to 3 minutes of rapid stair climbing titratable acidity, measured in 7 experiments, increased by an average of 0 036 mm /min , ammonia excretion in 5 experiments increased 0 025 and phosphate in 3 experiments increased 0 017 mm /min Excretion rates reached their maximal values 20 to 30 minutes after and returned to the pre-exercise levels 40 to 90 minutes after exercise Kattus, *et al* (16) and Sinclair Smith, *et al* (22) measured phosphate clearance in relation to mild exercise

in the cardiacs during the exercise A significant postexercise rise was in frequently observed

PROTEIN EXCRETION

Several authors (11,17,29) have commented upon the occasional presence of protein in the urine after exercise Protein is absent or is present in small amounts in the urine produced during exercise but appears during the first 30 minutes afterward and is excreted for 15 to 60 minutes The frequency of postexercise proteinuria is directly related to the severity of the exercise but even in very severe exercise is not observed in all subjects The protein excretion has been attributed to the reopening of glomeruli which have closed down during exercise as a consequence of intense renal vasoconstriction (28)

CRITIQUE OF EXPERIMENTAL STUDIES OF RENAL FUNCTION DURING EXERCISE

Inadequacies in our present knowledge are serious Water loading and recumbent posture, employed in nearly all studies, are not the usual pre exercise state of normal individuals Both factors tend to enhance renal function although the changes may be small The usefulness of water loading—promotion of a large urine flow to obtain accurate urine collections—is frequently lost during exercise due to rapid inhibition of urine flow Not only do urine collections dependent on voluntary voiding become unreliable but the rapidly changing flow may introduce systematic errors which would not have been present otherwise Dependence on voluntary voiding has required that collection periods be long enough to accumulate a urine volume which the subject is capable of voiding with a semblance of accuracy Consequently, rates of change of function during exercise are poorly known in few studies have as many as two urine collection periods been obtained during moderately taxing exercise In only two studies (4,9) have attempts been made to compare various degrees of exercise, and no systematic studies have been made of the effects of age sex, or physical conditioning In only three studies (4,10,17) have renal functions been correlated with other physiological functions during exercise The chronic effects of training are unknown

The interested reader is referred to several excellent sources for detailed results of experimental physiological studies and current concepts of renal physiology (23,24) and for technical details of measurement (19,21,23,24)

ADDENDUM

Several additional papers reporting studies on renal function during exercise were noted following completion of this chapter Although they do not alter significantly the foregoing conclusions, they are reported here for the convenience of research workers in this field

H Bucht, J Ek, E Eliasch, A Holmgren, B Josephson, and L Werko (*Acta Physiol Scand*, 1953, 28, 95) observed no clear changes in renal function in normal subjects exercising for a short period on a bicycle ergometer at a rate requiring 500 ml/min of O_2 consumption Significant decreases in filtration rate and, particularly in renal plasma flow and sodium excretion were observed at O_2 consumption rates of 900–1000 ml/min The latter values coincided with a 50 to 80 percent increase in cardiac output Extraction of p amino hippurate by the kidney did not decrease, indicating that no blood was diverted from excretory tissue during the renal oligemia

Judson and co workers (14 15) studied renal function before, during, and after exercise in 25 patients with various kinds and degrees of severity of

measured simultaneously This amount of exercise resulted in rather profound reductions in renal plasma flow, glomerular filtration rate, and excretion of sodium chloride and potassium in most of those patients with severe left sided failure but in small or indetectable depression during exercise in most of a group of generally less severely ill patients with right sided heart failure

Werko, *et al* (25) observed the usual changes in renal blood flow, glomerular filtration rate, and sodium excretion during exercise in patients with coarctation of the aorta The same group of researchers (27) studied the effects of administration of the vasodilator drug Apresoline (hydrazino phthalazine) to cardiac patients (mitral valvular disease, severity not stated) immediately before and during exercise Apresoline appeared to block the usual renal responses Renal blood flow increased and filtration rate and sodium excretion showed little change during exercise unless blood pressure dropped profoundly, in which case decreases occurred particularly with respect to the two latter variables

L R Radigan and S Robinson (*Am J Physiol*, 1949, 159, 585 an abstract) and L G Raisz, W Y W Au, and R L Scheer (*J Clin Invest* 1959, 38, 8) have measured renal plasma flow and filtration rate (mannitol clearance) before, during, and after walking and stair-climbing Their data are consistent with the findings of others

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Nutrition and Athletic Performance[1]

SUMMARY

Ability to perform well in an athletic event depends primarily upon the skilled and coordinated use of a well endowed and properly conditioned body; however, psychological factors such as motivation may be important in determining whether the athlete will win or lose a contest Awareness on [illegible] *ance also may have a beneficial psychological effect Therefore, by affecting the psychology of the athlete, the training diet and the pre event meal can affect his performance Since the athlete frequently experiences considerable nervous tension (with its digestive consequences) on the day of a contest, the pre event meal should consist of tried and true foods of a highly digestible nature taken some three or four hours prior to the event.*

There is no evidence that the diet immediately prior to a short term athletic event can be manipulated in such a way as to improve performance In longer events requiring sustained muscular work, there is considerable drain upon the carbohydrate stores and a falling blood glucose level may be associated with marked fatigue Accordingly, the degree to which carbohydrate stores are filled may affect endurance A small increase in muscular efficiency is believed by some investigators to occur when carbohydrate rather than fat is the predominant fuel for muscular work Whether such an increased efficiency can significantly influence athletic performance remains to be determined In any event, it seems desirable to prepare athletes par-

Jo[illegible]
pe[illegible]

ticipating in contests requiring endurance with diets that will ensure maximal filling of carbohydrate stores prior to the event

The trained athlete requires no extra protein, however, there is evidence that during rigorous training the diet should contain liberal quantities of protein in order to permit the muscle mass to increase rapidly and without cost to labile protein sources elsewhere in the body Supplementary vitamins probably are not needed in the nutritional program of the athlete who is consuming a nutritious diet A slight sodium deficiency can impair athletic performance before any clinical signs of sodium lack are discernible Therefore during hot weather adequate amounts of salt and water should be given to replace losses of these substances through the skin Excess body fat can be an important mechanical handicap for the athlete, yet caution must be exercised in diagnosing obesity in the athlete who is merely overweight in terms of the standard height weight tables Many "overweight' athletes are not actually obese and for this reason more informative measurements than those of weight and stature should be made when the athlete's caloric status is being assessed

Although there is considerable doubt whether manipulation of an adequate diet can enhance performance there is no doubt whatever that performance can be significantly impaired when a less than adequate diet is consumed The best diet for the athlete is one he enjoys and one that at the same time provides a variety of nutritious foods in amounts adequate to maintain his weight at an optimal level

INTRODUCTION

Manipulation of the diet in order to enhance physical performance is a procedure that has its roots in the superstition and magic of the unrecorded past At one time, men swallowed powdered lion's teeth to make them strong Similar practices are still carried on in primitive cultures For many centuries the popular belief existed that violent muscular exercise requires the eating of a large amount of meat and in the 19th century Liebig (42) gave scientific support to this tenet by proposing that during exercise the substance of the muscles is used up He stated, All experience proves that this conversion of living muscular substance into compounds destitute of vitality is accelerated or retarded according to the amount of force employed to produce motion' Subsequent experiments showed conclusively that heavy exercise is not associated with any significant increase in loss of nitrogenous material, however, the conviction that meat was the food par excellence of the athlete was so strong, and the prestige of Liebig so great, that a number of years passed before the doctrine of "meat for muscular work was reluctantly discarded

According to Drummond and Wilbraham (14) concern for the diet of athletes paralleled the growing interest in sport that began to be apparent

in England toward the end of the 18th century Early in the 19th century, it was customary for the athlete to begin his training with a series of strong purges to clear away 'all the noxious matter he may have had in his stomach and intestines" After this purification," unseasoned red meat (preferably underdone), bread, and mild beer were prescribed (35) Drummond and Wilbraham have written "The Oxford crew in the Sixties trained on a diet of underdone beef or mutton, bread, tea and beer, with a little jelly or water cress as a treat at the evening meal Instructions were given that no vegeta bles were to be eaten Cambridge, on the other hand, suffered no restriction regarding potatoes, greens, or even fruit From 1861 to 1869 there was an unbroken succession of Oxford victories So much for vitamins in athletics' It is convenient to consider the effect of diet on physical performance at two levels psychological and physiological

PSYCHOLOGICAL CONSIDERATIONS

Much still needs to be learned about the effect of the psychological state of the athlete upon his performance Yet it is widely agreed that motivation plays a major part in determining whether an athlete will win a contest The food that is consumed during training and immediately before an athletic contest may have a psychological significance for the athlete that exceeds its physiological and metabolic importance (39) The significance of eating rare meat as a symbol of manly vigor and strength is obvious In the course of his training program, the athlete frequently must work hard and forgo many pleasures Accordingly, his need for gratification is accentuated Some of this need can be met by providing him with appetizing foods, such as special desserts and rare beef This provision makes him feel that training has its incidental rewards and helps to prevent him from going stale ' Pre sumably there is an element of atavism in the emphasis on eating meat at the training table

The drinking of milk (although not always recommended at the training table) has in some cultures become associated with the idea of health and 'clean living" Then, too, the training table may provide some of the sense of security and reassurance generally obtainable by the practice of rituals Use of various rituals by athletes in preparing themselves emotionally for contests is well known Thus food has a significance far beyond the nutri ents it provides Also, the *atmosphere in which food is served is frequently* more important than the quality of food served (44) The morale value of turkey at Thanksgiving has been recognized by the military services, and on this holiday American soldiers stationed in far-off lands are served turkey, regardless of the cost involved

A number of studies have purported to show that between meal feedings during working hours improve the efficiency of performance of industrial workers (24) However, when such studies have been repeated with use of

suitable controls, it has usually been possible to demonstrate that the beneficial effects were psychological rather than physiological in origin When ingestion of sugar before an athletic performance seems to have a salutory effect, it is difficult to decide whether this response occurs for psychological or physiological reasons

In view of the importance of psychological factors in modifying physical performance, it would be unwise and unjustified to deprecate the psychological value of food, and of the ritual of the training table for the well being of the athlete However, it seems important to study these psychological aspects of food and the training table carefully in order that their contribution may be better assessed and clearly distinguished from possible physiological and metabolic factors

PHYSIOLOGICAL AND METABOLIC CONSIDERATIONS

Digestion and Athletic Performance

Considerable attention has been paid to the pregame or pre-event meal As Bensley (3) has pointed out, the chief consideration to be borne in mind in planning this meal is the emotional stress that the athlete may experience on the day of the contest Loss of appetite, abdominal discomfort, and even nausea, vomiting, or diarrhea may occur If the meal is taken too close to the game or event, the anxiety of the athlete may interfere with appetite and digestion Moreover, the distended stomach may impair performance Therefore in most cases the pre event meal should be consumed not less than three hours before the contest Individual food preferences should be respected The athlete knows from experience which foods can be eaten without causing him discomfort As a general rule, only foods known to be highly digestible should be consumed as part of the pre event meal

Sources of Energy During Athletic Activity

[illegible] ters of endowment and training Concur-changes in diet may affect the amount of energy and the rate at which this can be made available Obviously an enormous variation exists in the expenditure of energy by athletes, and many classifications have been used to divide athletic performances in terms of energy expenditure One such classification distinguishes four groups (1) single effort field events, such as the high jump, the broad jump, putting the shot, and pole vaulting (2) sprints and hurdle races, (3) middle distance runs, such as the mile run and (4) prolonged efforts taking more than one hour, as exemplified by the marathon

(It is acknowledged that a number of sports would not fit into the fore

going categories For example, wrestling a most strenuous sport, requires not only explosive body movements but a constant fighting against the resistance of the opponent Hence it combines some features of sprint, middle and long distance runs with occasional single all out efforts)

From what is known about intermediary metabolism it would appear that the sources of energy for these classes of endeavor may be somewhat different For example, in the single effort events and sprints requiring bursts of effort, the body can make use of stored energy readily available from the energy rich organic phosphates adenosine triphosphate and creatine phosphate However in order for the high energy phosphate bonds of these compounds to be regenerated fuel *must be metabolized* To a limited extent energy rich phosphate bonds can be regenerated by the breakdown of glycogen to lactic acid a process that does not require oxygen However the major supply of energy expended by the body is derived from the complete oxidation of small fragments derived from carbohydrate and fat Indeed per molecule of glucose oxidative phosphorylation is much more effective than the phosphorylation connected with lactic acid formation

In the 100-yard dash, the oxygen requirement is over 6 liters Since the human respiratory and circulatory equipment can provide only approximately 650 milliliters of oxygen during the 10 seconds needed to complete this event, it is clear that the body is able to perform work and replenish energy stores for a limited time in the absence of oxygen This is accomplished primarily by the breakdown of glycogen to lactic acid However this process is limited since the maximal oxygen debt the body can incur seems to depend upon the amount of lactate that the tissues can tolerate Lactacidemia may unfavorably affect blood acid base balance and consequently, the metabolic and physiological functions that depend on the maintenance of pH level within a certain optimal range

The oxygen needed for recovery after muscular exertion under anaerobic conditions is related to the total quantity of lactate produced during this period [illegible] in orde [illegible] longer [illegible] enter the tricarboxylic acid cycle and undergo complete oxidation with restoration of homeostasis

During the recovery phase oxygen in excess of current needs is taken in to make up this deficit which may be as high as 16 liters Such an oxygen debt can be incurred rapidly or more slowly In practical terms, if an athlete exercises to a degree so that he needs 8 liters of oxygen per minute he can maintain such a pace for only a few minutes, since in that time he will have reached his oxygen debt ceiling Since the oxygen requirement increases rapidly with an increase in running speed the ability of the sprinter to achieve a pace almost 50 percent faster than that of the mile runner becomes readily explicable in physiological terms

It must be emphasized that the body is not able to maintain an intake of the order of 4 liters of oxygen per minute for very long If exercise has to be maintained for a matter of hours, oxygen consumption approaches one liter per minute Thus as the energy expenditure of the athlete becomes more prolonged, its intensity must diminish As its intensity lessens, the relative importance of the oxygen debt mechanism also diminishes For moderate distances, the runner may depend in part on his "recovery" period, for long distances, he must run in a steady state' (the condition in which the intake of oxygen meets the metabolic needs of muscle)

It would seem that, in the first three classes of athletic events listed above, the fuel supply is an item of minor concern, since the amounts of energy used are relatively small In the fourth class, where endurance may be a deciding factor, the fuel supply becomes relatively more important In any event, since diet does more than merely provide fuel for muscular activity, a more detailed analysis of the ways in which diet can influence performance is appropriate Before such an analysis can be undertaken, however, the methods and criteria used in the assessment of physical performance should be briefly considered

Influence of Diet on Physical Performance

It has already been mentioned that motivation, skill, and coordination play important roles in determining the outcome of athletic contests Thus it is inherently difficult to study the problem of diet in relation to performance under satisfactorily controlled conditions As Marrack (30) has stated, Excellence in athletics does not depend so much on the energy output by muscles and the rate at which this output can be maintained as on the skill with which this energy is used " Use of studies with animals in assessing the effect of diet on performance is not a particularly helpful procedure because of the difficulty in interpreting in human terms quantitative changes that may be measured in experimental animals Keys (26) has properly stressed the importance of using rigid standardization and has criticized many earlier studies because they were not sufficiently prolonged to eliminate the period of adaptation to a new dietary pattern suddenly imposed on the experimental subject

Generally, the criteria used involve measurement of performance of an actual physical task, such as swimming 100 yards or running a mile The responses of such physiological factors as pulse rate, body temperature, and reaction time to muscular activity also serve as indication of the ability to perform under standard conditions Biochemical changes in the blood, particularly variations in values of blood glucose, lactic acid, and ketone bodies, have been measured during and after a standard task and used as indexes of performance

The term "efficiency" applied to muscular activity is a technical expression that refers to the energy cost of mechanical work Ordinarily efficiency is

calculated in one of two ways as gross efficiency (total energy output in relation to mechanical work done) or as net efficiency (the increment of energy output over some predetermined base line energy output, such as the resting or the basal metabolic rate, in relation to mechanical work performed 15) Gemmill (16) has discussed the merits and disadvantages of such calculations in a comprehensive review Of numerous methods for measuring the mechanical energy developed by man during exercise, the most commonly used is the bicycle ergograph Considered as a machine, man operates at a maximal efficiency of about 25 percent (calculated for climbing stairs), this is somewhat better than the ordinary gasoline engine but not as good as the diesel engine

In his review of the problem of physical performance in relation to diet, Keys (26) has listed three ways in which special dietaries might influence muscular performance These involve (1) renewing the supply of energy yielding nutrients, (2) facilitating the energy yielding reactions and (3) counteracting physical chemical changes in the body identified with fatigue A fourth way in which diet can favorably influence physical performance is by reducing any appreciable excess in fat content of the body Such a decrease in adiposity will result in a proportional decrease in the energy cost of moving the body or its parts

The first of these categories has to do with the fuels of muscular exercise —carbohydrate, fat, and to a lesser extent, protein Because vitamins are essential constituents of enzyme systems which in turn are an important part of the machinery of energy metabolism these nutrients properly fall into the second category, which is concerned with the problem of facilitating the energy yielding reactions Since fatigue is believed to be a manifestation of altered physiology induced by excessive muscular work, the influence of muscular work on homeostasis can be considered in the third category Lastly, since excess fat results from a positive energy balance maintained for a prolonged period, the problem of reducing the athlete s weight must be thought of in terms of the caloric provision at the training table measured against the day by-day energy expenditure calculated for that particular

sideration of his bodily composition (2) (Although clinical deficiency states obviously can be associated with impaired performance, such disorders have been excluded from consideration in this paper The present discussion is concerned primarily with the problem of determining whether there is such a thing as an optimal diet for a given category of athletic performance)

Carbohydrate Most observers have noted that, when carbohydrate is readily available to tissues, it is used preferentially for muscular work However, as reserves of carbohydrate diminish, increasingly more fat is metabo-

lized Accordingly, either carbohydrate or fat, or any combination of the two substrates, can provide fuel for muscular exercise Krogh and Lindhard (29) reported that, when subjects are on a high-carbohydrate diet, they show a higher net muscular efficiency than when they are on a high fat low carbohydrate diet Calculations based on respiratory calorimetry indicated that up to 9 percent greater expenditure of energy per unit of work occurs when fat is being burned (the respiratory quotient equals 0 7) The findings of Krogh and Lindhard were continued and confirmed in their laboratory by Bierring (5) However as Gemmill (16) has pointed out, these authors used a projected line to obtain the two extremes for their calculations As actually determined the highest respiratory quotient obtained was 0 93 when the work expenditure was 4 6 calories, the lowest respiratory quotient was 0 75 when the caloric output was 4 82 Accordingly, the actual difference between these two measured points is 4 5% Marsh and Murlin (31) were unable to distinguish any relation between efficiency and relative quantity of fat and carbohydrate in the diet when light work was performed but noted a decrease in efficiency on a diet high in fat after such a diet was continued for three or four days

Haggard and Greenberg (20) performed studies with the bicycle ergograph that led them to believe that a high carbohydrate intake increased muscular efficiency markedly and that an increase in the interval between meals was associated with
been unable to discover a
After reviewing the literatu
ciency of diets high in carbohydrate or fat Gemmill (16) concluded that muscular efficiency is practically the same on all diets He states that there is a slight increase in efficiency after a high carbohydrate diet, which probably does not exceed 5 percent

In prolonged physical activity a definite correlation can be observed between symptoms of fatigue and a decrease in blood sugar level When glucose is administered under these circumstances, the symptoms disappear and the power to work is increased Christensen and associates (9) believe that the beneficial effect of administered glucose is a neurophysiological phenomenon and not due to a direct metabolic effect on muscle Apparently

Simonson and co-workers (34)
changes in blood sugar level A
panied by hypoglycemia, althou
by fatigue

Considerable literature has appeared concerning the effect of breakfast and its composition upon performance of work and emotional status Tuttle and associates (37 38) found that omission of breakfast affected

adversely performance on the bicycle ergograph Thorn, Quimby, and Clinton (36) and others (10,11) have observed that a breakfast high in protein has value in maintaining the blood glucose level and also a feeling of well being Yet many of the effects of omission of a meal may result primarily from the sudden interruption of an established eating pattern Studies on individuals who habitually omit breakfast might be more rewarding Moreover, it would be inappropriate to apply results obtained in studies on industrial or clerical workers to athletic performances (33) Before an athletic event, the athlete may be in a psychological and physiological state not at all comparable to what might be anticipated under more casual circumstances

Concerning dietary sugar and performance, the remarks of Abrahams (1) seem pertinent

> What of sugar, approbated as a readily available source of energy to be taken before a contest? It is conceivable that in a very protracted effort the reservoirs might be exhausted and hypoglycemia occur But that a special sort of explosive
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>
> that he will be powerfully influenced by anybody in whom he has confidence in which case it is immaterial what he is given I have been convinced of this psychological element with substances simpler than sugar and sometimes quite inert

Haldi and co workers (21,22,23) have studied the effect of carbohydrate intake on physical performance, using the time taken to complete a 100-yard swim as the index When a high-carbohydrate meal was taken three hours before the swim, performance was not better than that after an isocaloric meal low in carbohydrate Blood sugar concentrations were higher after a swim of this distance in all cases but were not affected by the composition of the preswim meal Haldi and associates concluded that in brief periods of very strenuous exercise muscular efficiency is dependent upon the energy reserves and the training of the subject The composition and size of the pre exercise meal do not appear to play a significant role

Although the proponderance of available evidence indicates that the composition of the pre-exercise meal does not affect efficiency during athletic events of brief duration, there appears to be little doubt that the capacity to endure prolonged muscular work is enhanced if carbohydrate stores are replete prior to the exercise period Whether this favorable effect is due entirely to the maintenance of higher blood glucose levels or whether it can be explained in part by the slightly greater efficiency of muscular work when carbohydrate is the predominant fuel is not entirely clear Christensen (9) and others believe that in the last few days before an athletic contest heavy work should be avoided to allow for maximal filling of carbohydrate stores However, more experimental work is needed before it can be stated with assurance that this belief is well founded.

Fat There is no doubt that fat provides fuel for muscular work In sustained exercise, when carbohydrate reserves diminish, the respiratory quotient falls, indicating that an increasing proportion of fat is being oxidized However, fat seems to play a passive role in energy metabolism, in the sense that when carbohydrate is available as a fuel for exercise, the respiratory quotient usually rises and the contribution of fat to energy metabolism diminishes in proportion When exercise ceases the respiratory quotient again falls to low levels indicating that the metabolic mixture in the blood is largely composed of fat In the diet of athletes (as in general), fat at the metabolic level acts as an indifferent source of energy Beyond this, it makes no special contribution to muscular performance

Recent studies notably by Dole (13) and Gordon (18) and their respective associates, have provided evidence that fat is made available to peripheral tissues for fuel in the form of nonesterified fatty acids (NEFA) NEFA levels in blood vary inversely with the rate at which glucose is utilized, for example NEFA levels are elevated in the fasting state and in uncontrolled diabetes They diminish promptly when glucose or insulin is administered Study of the behavior of plasma NEFA under varying conditions of physical exercise should provide interesting additional information about fat metabolism during exercise

Protein Since Zuntz (47) and others (7,8) have shown that protein is not metabolized in significant amounts during muscular exercise in the well nourished person it need be considered only briefly as having an energy releasing reaction The importance of meat as a constituent of the diet of athletes has been much debated but it would appear that an excess of meat at the
value
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protein during training for heavy muscular work and found that early in training the hemoglobin and albumin contents of the blood decrease The

As a result of these findings, Yamaji has concluded that during training

protein accumulates in muscles at the expense of blood proteins He has recommended that, during training programs involving heavy muscular work, an excess of protein be consumed Such a diet would help to prevent anemia and permit the muscle mass to increase in size more rapidly If Yamaji's results can be confirmed, it would mean that hemoglobin synthesis does not necessarily take precedence over other protein requirements as some studies have implied In any event, it seems clear that determinations of nitrogen balance during periods of rigorous training indicate only whether a net catabolism or anabolism of protein is taking place

Additional studies, including determination of body constituents are needed to provide information about important internal changes in protein metabolism that may be taking place The studies of Yamaji and his colleagues deserve to be carefully followed up in the United States particularly with respect to changes in reserve or labile protein that may occur during conditioning periods in athletes who have been out of training for some time If the athlete is a growing boy, he will need extra protein to meet this particular anabolic requirement whether he is in training or not

Vitamins It is now widely recognized that many vitamins of the B group are important constituents of coenzymes that participate in the energy releasing reactions for which carbohydrate and fat provide the major substrates (4) The specific vitamins known to be involved are thiamine (cocarboxylase), riboflavin (flavoprotein coenzymes) nicotinamide (diphosphopyridine nucleotide, or coenzyme 2) pantothenic acid (coenzyme A), and probably vitamin B_6 (codecarboxylase and transamination coenzymes) and biotin (carbon dioxide fixation coenzyme) The rationale for believing that vitamin supplements might significantly affect physical performance involves the assumption that subclinical vitamin deficiencies are not uncommon in apparently well nourished persons or failing this that it is possible to supercharge the energy producing reactions by providing an excess of vitamins

Keys and his associates (26) were unable to discover any benefit to performance of work or capacity from large daily supplements of the B vitamins given to soldiers maintained on ordinary United States Army garrison rations In his review Keys states that he has been unable to find convincing evidence that supplements of the B complex or vitamins C or E, separately or in combination would enhance the physical performance of apparently well nourished persons Bourne (6) has recommended a high vitamin intake for athletes on the ground that the requirement for certain vitamins may be enormously increased in strenuous exercise Actually there is very little evidence to suggest that the requirement for vitamins is appreciably increased during prolonged muscular work (41) At best, the requirement for certain vitamins may increase in direct arithmetical proportion to the increase in expenditure of energy In spite of occasional reports of apparently beneficial effects of vitamin supplementation upon athletic performance (40), it remains to be demonstrated convincingly that supplementation of the diet of

the athlete in training with vitamins of any sort has a beneficial effect on endurance, muscular efficiency, or coordination

Electrolytes and Blood Acid Base Balance After brief periods of strenuous exercise, there occurs a marked increase in production of lactic acid by the working muscles At the same time a moderate increase in production of pyruvic acid takes place These values are greatest 5 to 15 minutes after such exercise but remain comparatively high during the balance of the recovery period (17) According to Christensen and co workers (9), the rise in lactic acid brought about by work of definite severity becomes less for the subject in better training However, there is no evidence that the trained subject can dispose of excess lactate more rapidly than the untrained person

The mechanism of lactacidemia has already been discussed However, since severe exercise is associated with an accumulation of large quantities of organic acids, alkalinizing procedures have been suggested as having possible value in relieving the fatigue of the athlete Dennig and his associates (12) studied the effect of alkaline producing salts such as sodium citrate and sodium bicarbonate on the endurance of volunteer subjects running on

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fects however, the following possibilities were considered (1) an effect on mood, (2) reduction in the work of breathing during exercise, and (3) a protective effect on the pH of blood and tissues Johnson and associates (25) studied the effects of blood alkalinizers on the efficiency of runners and

little influence on the ability of the normal person to perform muscular work

When carbohydrate stores are depleted during prolonged strenuous exercise, a rise in blood level of ketones may be anticipated According to Grollman and Phillips (19) the degree of ketonemia occurring under controlled dietary conditions during performance of a standard task involving muscular exertion varies directly with the degree of training of the individual performing the task They postulate that the greater rise in levels of blood ketones in the trained individual may represent that portion of the oxygen debt not accounted for by lactacidemia Incidentally, there appears to be no evidence that the mild to moderate ketonemia of exercise during a time of carbohydrate depletion is in any way deleterious

Frequently athletic contests are carried on during hot weather and are associated with excessive losses of sodium chloride and water from the skin Obviously under these circumstances replacement of salt and water is

needed Keys and associates (26) have found that work capacity in heat is markedly reduced when salt is severely restricted, even when this does not involve heat cramps or heat hyperpyrexia At least 2 to 3 gm of sodium chloride must be replaced per liter of sweat lost Salt tablets may be upsetting to the digestive tract, and many physicians have found a weak solution of sodium chloride to be better tolerated by the individual deficient in salt

Calories and Body Weight Ordinarily, the athlete will spontaneously ingest food in amounts adequate to maintain his weight It is unusual for obesity to develop during a period of rigorous physical conditioning, however, if the training table food is appetizing and also calorically concentrated and the training itself moderate, it is quite possible for the athlete to accumulate fat during the training period If the athlete has allowed himself to gain fat intercurrently, he will tend to lose it during the training period It is axiomatic that the athlete who decreases his total weight by losing excess fat will be a more efficient machine Accordingly for most forms of athletics obesity, even to a mild degree, constitutes a mechanical handicap

The development in Germany of a light, portable respirometer has made possible the convenient collection of fairly accurate information about the caloric cost of different kinds of athletic activity (28) In assessing the nutritional needs of athletes, it is clearly important to obtain reliable information about the calories expended by the athlete in the performance of his particular event or events Passmore and Durnin (32) have carefully reviewed much of the recent information on the subject of expenditure of energy of man They have recorded figures for the energy costs of different sports expressed as calories per minute For example, they note that skiing at moderate speed on level, hard snow involves a significantly greater energy *cost than swimming the crawl at a rate of 55 yards per minute On the basis* of quantitative information of this sort, it should be possible to obtain a better understanding of the caloric needs associated with a variety of sports

As a result of application of dilution and densitometric methods considerable information has been gathered concerning the body composition of athletes (27) Welham and Behnke (43) studied 25 athletes and found that on the basis of standard height weight tables of the type used by the insurance companies and the military services, 17 fell into the overweight category When these investigators performed determinations of specific gravity on the 17 subjects who by conventional standards would have been classified as obese they discovered that 11 of the group possessed high corporeal specific gravity This indicated that these particular "overweight" subjects actually had a relatively low content of body fat and a proportionately increased lean body mass On the basis of these findings, the authors have proposed that overweight should be defined in terms of the specific gravity of the body mass, with a tentative dividing line at the value 1 060 (specific gravity) between the obese and nonobese categories

If the conventional criterion of desirable weight, based on relationship be-

tween height and weight (modified by age), is used uncritically as a guide, it is conceivable that a number of lean athletes might be placed on reducing diets in the mistaken belief that they were obese Such a procedure could only impair the athletes ability to perform Thus in the assessment of the caloric status of athletes, it would seem particularly important to use criteria supplementary to the simple determination of body weight, such as the difference between circumferential measurement of chest and abdomen and the measurement of thickness of skinfold with appropriate calipers

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16

JEAN MAYER

Exercise and Weight Control

SUMMARY

Exercise does entail a considerable expenditure of energy For example while the caloric requirement of a sedentary man is of the order of 2400 calories per day a physically active individual may consume twice as much or even more

In spite of popular belief the performance of exercise is not automatically followed by an increase in food intake This increase only takes place if the individual was fairly active to start with If he was sedentary he can step up his activity without any such increase in appetite Conversely if activity is decreased below a certain point (the exact point depends on the individual) appetite does not decrease correspondingly in fact it may increase somewhat The result of course is accumulation of fat

Finally the cost of moving the body is proportional to body weight It follows that the energy cost of a given exercise is greater for an overweight person than for a normal weight individual Conversely a physically active person will tend to have a more stable weight than an inactive person Thus regular exercise has an essential role in weight control

In the past one or two decades and at least on this side of the Atlantic, the role of exercise in weight control has been minimized if not ridiculed The basis for this denial has been not experimental or clinical work (nor the weight of the accumulated experience of the century which has always contrasted the lean hard active soldier or hunter with the fat merchant or clerk) but simply two plausible misconceptions These are as follows

1 Exercise requires relatively little caloric expenditure and therefore increased physical activity hardly changes the caloric balance
2 An increase in physical activity is *always* automatically followed by an in

crease in appetite and food intake and may therefore actually impair weight reduction

ENERGY EXPENDITURE IN EXERCISE

The first misconception, minimizing the caloric expenditure due to physical activity should be avoided by anyone who has ever looked at a table of energy expenditure Such tables illustrate the fact that the cost of exercise can be high Similarly the National Research Council table of recommended dietary allowances for men vary from 2400 to 4500 calories per day depending on the level of activity (6) The figure of 4500 calories per day does not represent an upper limit (laborers, soldiers in the field, and athletes often require up to or even more than 6000 calories per day)

In contrast to these statements, one frequently hears or reads such statements as the following the caloric equivalent of a pound of fat can only be matched by walking 36 hours splitting wood for 7 hours, or playing volley ball for 11 hours These unattainable extremes of physical activity are used to demonstrate that it is impossible to lose weight by exercise The implicit postulate is that the cost of exercise depends entirely on the exercise being done at one stretch Actually, of course, the cost of splitting wood for seven hours will still be equivalent to one pound of fat even though the seven hours may not constitute one stretch Thus while splitting wood for seven consecutive hours would be difficult for anyone other than a Paul Bunyan, splitting wood for one half hour every day, by no means an impossible task for a hea

sented a

exercise,

A half hour of handball or squash a day would be equivalent to 16 pounds a year

It seems more useful, however, simply to recall the measured costs of dif

of average size (145–170 pounds)

short duration peaks of activity reached in competition, when caloric expend

minutes without undue discomfort

In most types of exercise, no heavy object is moved other than the whole or parts of the body Therefore, the energy cost of exercise is proportional to body weight (5,15) If excess body weight is so great that it impairs body movement, this relationship will no longer strictly apply, and the cost of exer cise will actually increase faster than body weight (6)

If the energy cost of exercise is approximately proportional to body weight, it follows that the overweight person will require more energy, and hence burn more body reserves for the *same amount* of exercise than would a slimmer individual Twenty percent overweight will increase the cost of walking, tennis playing, golfing, and such by 20 percent This represents a much greater proportional increase than that introduced by the increase in basal metabolism due to excess weight, which is proportional only to a frac tional power of the body weight (15,25)

Thus any increase of the caloric intake above balance level in a physically active individual will cause only a modest increase in weight because of the energy cost of moving the extra poundage On the other hand in a sedentary individual, less energy will be expended moving the extra weight and hence weight gain will be more rapid and more pronounced A sedentary person will therefore be exposed to the danger of overweight to a much greater extent than an individual who makes a practice of daily or at least fre quent, physical exercise

Data from studies of experimental obesity support these concepts In the hereditary, obese hyperglycemic syndrome of mice, the bulk of the extra calories comes from inactivity rather than from hyperphagia If nonfasted animals are placed in activity cages and spontaneous activity measured, it is found that obese animals are fifty to one hundred times less active than nonobese animals (19 20) This inactivity is not the result of extreme obesity but in fact precedes it, as is shown by the comparison of activity rates of mature nonobese animals and of young obese animals of the same weight It can thus be considered as one of the etiological factors in the syndrome determined by the 'obese hyperglycemic" gene Nonobese animals pla teaued in weight consume about 20 calories per day of which 10 cover basal expenditure, and 2 cover *specific dynamic action, leaving 8 for the cost of* activity Obese littermates consume about 25, and may gain up to 1 gm (or 9 calories) per day Their basal is, again of the order of 10 calories per day, S D A 2 5 calories per day When the eight calories expended daily on ac tivity by the nonobese mouse are ascribed in the obese mouse to fat synthesis, the rapid development of the extreme adiposity is no longer a thermody namic impossibility

The weight gain of genetically obese mice can be drastically reduced by treadmill exercise (22) The obese members of the strain who carry the "waltzing' gene and are in constant rotary movement in their cages show a weight gain only about 30 percent greater than the nonobese mice, rather than 200 or 300 percent as shown by the sedentary obese mice

Hypothalamic obesity in the mouse is also characterized by a considerable degree of inactivity (23) By contrast, goldthioglucose obese mice are normally active but spontaneously lose weight if given the opportunity to exercise more in a squirrel type of rotary cage (16) It is worthy of note that recent findings (17) reveal that reducing the weight of obese animals through exercise has a much more lasting effect than reduction through curtailment of food

Such findings emphasize both the diversity of obesities as regards spontaneous activities and the importance of exercise as a weight control factor

EXERCISE FOOD INTAKE AND BODY WEIGHT

A second frequent misconception concerning the value of exercise in weight control is that an increase in physical activity *always* causes an increase in appetite and food intake which equals or is greater in energy value than that of the energy cost of the exercise

That in a normal reasonably exercised animal or person an increase in food intake follows an increase in activity is true it explains why the weight of most adult animals and men is relatively constant Proper adjustments of appetite prevent the body from indefinitely burning away reserves if the individual is called upon to perform at higher levels of exertion than hitherto customary However experimental results show that this is true only within a certain range which has been termed by the author normal activity range (21 22) It had already been shown (8) that rabbits, when restricted in their activity by confinement in a small cage, will consume more calories than they require and accumulate fat The excess food consumed is characteristic of the strain hence a hereditary factor is involved here The same phenomenon is illustrated by the fact that rats can be made obese by total immobilization (12)

The dependence of food intake and body weight on physical activity has since been systematically explored in experimental animals (22) When mature rats accustomed to a sedentary (caged) existence were exercised on a treadmill for increasing daily periods it was observed that for low durations of moderate exercise (20 minutes to 1 hour) there was no correspond

linearly and weight was maintained (range of proportioned response a normal activity range on Fig 16 1) For very long durations of exercise, the animals lost weight, their food intake decreased and their appearance deteriorated (exhaustion range on Fig 16 1) Both the sedentary and the exhaustion ranges can thus be considered nonresponsive ranges with respect to food intake as in these ranges, an increase in activity is not accompanied by a corresponding increase in food intake Of particular interest to

the problem of obesity is obviously the sedentary "nonresponsive" zone It demonstrates that under abnormal environmental conditions forcing partial immobilization or at least a sedentary life on the subject, the limits below which the regulation of food intake no longer responds by a decrease to a decrease in activity, is overtaken Adiposity is the unavoidable result This, of

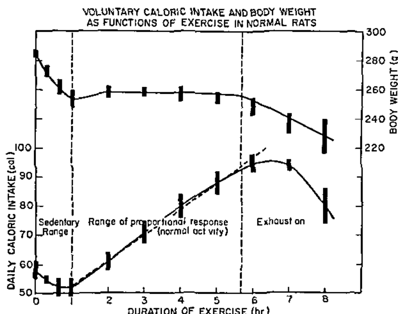


FIG 16 1 *Illustration of the relationship of intake body weight, and exercise in experimental animals* (22)

course, has been known empirically to farmers for centuries and explains the practice of cooping up or penning up cattle, hogs, and geese for fattening

Similar observations are available on man Greene (10) has studied more than 200 overweight adult patients in whom the beginning of obesity could be traced directly to a sudden decrease in activity The author had the opportunity in the summer of 1954 to conduct a study on an industrial population of West Bengal (India) showing a particularly wide range of physical activity (from bazaar tailors and clerks to coolies carrying twice their body weight on their heads for nine hours a day) Fig 16 2 illustrates the findings (24) The determination of food intakes was facilitated by the fact that most of the individuals surveyed did not live in a family situation, but bought their food and cooked for themselves The lack of provision for storage forced them to market frequently The diet was extraordinarily uniform for each individual and showed little variety within groups and from group to group Individual one day dietary recalls, checked by buying records and checks on amount of money spent per week on food gave results generally

identical with exhaustive dietary histories and appeared more representative of long range intakes than corresponding data obtained in a Western society Activity was determined by detailed schedules, industrial ratings of physical effort, and some Douglas Bag determinations Clerks were further subdivided into four classes according to the mileage walked daily to and from work, Class One being the most inactive group who actually lived within the factory grounds The various occupations or subgroups were represented by at least 10 individuals each and were grouped according to a broad classification of activity, extremes being represented on the one hand by merchants, supervisors and "nonwalking clerks, at the other end by selectors and pilers, carriers who carried up to 190 pounds of jute per man, coal men, ash men who carried equally heavy bags of coal and ashes and unloaded them in an awkward manner, and cutters who spent their whole day swinging heavy cutting knives with practically no pause Individual weights varied from 67 pounds to 198 pounds for the same height (5'2" to 5'4") Economic differences, cultural, religious, and ethnic factors could be accounted for and ruled out in the analysis of the results It is readily seen from

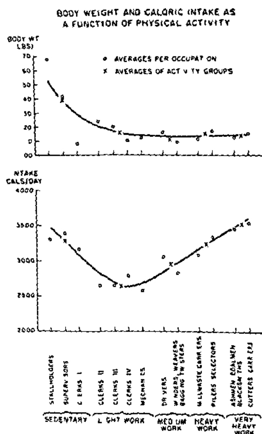


FIG 16 2 *Illustration of the relationship of intake, body weight, and exercise in adult men* (24)

Fig 16 2 that the curves obtained for food intake and body weight as functions of food intake are strikingly similar to Fig 16 1 obtained on rats Again, there is a sedentary range which corresponds to no further decrease in food intake (instead to an increase) and where increasing degrees of overweight follow decreasing exercise (Incidentally, the meaning of the actual increase in food intake under extremely sedentary conditions is not clear It may indicate decreased ready availability of reserves, possibly as a result of circulatory sluggishness due to inactivity)

The work of Taylor and colleagues at the Department of Physiological Hygiene, University of Minnesota (29), has also shown that an increase in exercise above the very sedentary level was not accompanied by an increase in food intake in adult males

The problem of the relation of weight to activity in children has also been investigated Bruch (3) had found that inactivity was characteristic of the majority of the 160 obese children which she had studied Only 18 percent of the boys and 22 percent of the girls were "normally" active Seventy six percent of the boys and eighty eight percent of the girls were physically in active Rony (30) suggested that laziness or decreased tendency to muscular activity is a primary characteristic of obese subjects, it is demonstrated in childhood by avoidance of all unnecessary activity, outdoor play and athletics Bronstein (2) found that most of the 35 obese children which he and his as sociates studied spent most of their leisure time in sedentary activities Graham (9) reported similar observations Danish workers, in particular Tolstrup (32) and Juel Nielsen (14), attempted a semiobjective grading of groups of obese children and found that lack of activity was characteristic of these subjects Peckos (28), studying a large group of Boston children, found that differences in body build, and more specifically in fat content and distribution, was not correlated with caloric intake Fry (7), studying obese children selected as presenting large fat pads, found that these chil dren did not have higher average caloric intakes than did control children of the same height and age In her tabulation of "rough psychological eval uation" a much higher proportion of obese children than of nonobese chil dren are labeled as only moderately active or inactive This difference was particularly marked as far as the boys were concerned No data, however, were given to support this estimate

In a recent study conducted in cooperation with Dr Mary Louise Johnson and Mrs B S Burke (13) an attempt was made to compare systematically both caloric intake and activity in carefully paired groups of obese and normal weight school girls Exhaustive research relating to dietary histories and activity schedules covering the year preceding the study was conducted The Burke research dietary history method was used (4), with due regard for the difficulties encountered when applied to children (18) and to obese subjects (1,33) The picture of physical activity was obtained by a system of successive examinations First a list of usual activities was established and the subjects were asked how much time they devoted to each on a daily or weekly basis depending on the type of activity considered The subjects were then asked to complete the list of activities and schedules, covering the year by seasons Total hours per week were checked, and in another interview the activities were rechecked again on the same general basis If the total time per week had been grossly over or underestimated, special efforts were de voted to locate the causes of the error The activities were rated on the basis of Rose (31) and Orr and Leitch (26) Findings were that suburban high

school girls were generally not very active Even the schedule of the nonobese group showed little time devoted to household chores, little participation in active sports and, at least during the school term, a minimum amount of time devoted to walking or to other physical activity. Even so, however, there was a marked difference between the obese and nonobese groups The obese group was much more inactive than the nonobese Generally speaking, the time spent by the obese group in sports or any sort of exercise (including ballroom dancing) was less than half that spent by the thin girls, the difference being absorbed by "sitting" activities By contrast, caloric intakes were generally larger in the nonobese group than in the obese When possible, factors leading to positive energy balance were analyzed It appeared that for this particular group, even when probable sources of error inherent in the dietary interview method and in the type of activity analysis selected were recognized, inactivity was of greater importance than overeating in the development of the obesity These high school girls, both obese and nonobese, attended summer camp each year and almost without exception reported loss of weight under the systems of enforced strenuous activity, in spite of simultaneous increased food intake

[illegible]

a summer of enforced sports without any dietary restriction No obese boys gained weight under such conditions they either maintained their weight at previous levels or lost By contrast, a large proportion of nonobese boys gained weight under the same regimen

CONCLUSION

The author is convinced that inactivity is the most important factor explaining the frequency of "creeping" overweight in modern Western societies Natural selection, operating for hundreds of thousands of years, made men physically active, resourceful creatures, well prepared to be hunters, fishermen, or agriculturalists The regulation of food intake was never designed to adapt to the highly mechanized sedentary conditions of modern life, any more than animals were made to be caged Adaptation to these conditions without development of obesity means that either the individual will have to step up his activity or that he will be mildly or acutely hungry all [illegible]

[illegible] the young, highly competitive sports for the few are emphasized at the expense of individual sports which all could learn and continue to enjoy after the high school and college years are over But if the first alternative, stepping up activity, is difficult, it is well to remember that the second alterna

tive, i.e., lifetime hunger, is so much more difficult that to rely on it for weight control programs can only continue to lead to the fiascos of the past.

TABLE 16.1 Energy Cost of Sports*

Sport	Cost (Cal/Hr)	Sport	Cost (Cal/Hr)
Walking 2 mph	200	Soccer	550
3 mph	250	Canoeing 2.5 mph	180
4 mph	300	4.0 mph	420
Running	800–1000	Sculling 50 str/min	420
Cycling 5 mph	250	97 str/min	670
10 mph	450	Rowing (peak effort)	1200
14 mph	700	Swimming breast and	300–650
Horseback riding walk	150	back stroke crawl	700–900
trot	500	Squash	600–700
gallop	600	Climbing	700–900
Dancing	200–400	Skiing	600–700
Gymnastics	200–500	Skating (fast)	300–700
Golf	300	Wrestling	900–1000
Tennis	400–500		

SOURCE Modified and summarized from Orr and Leitch (26) and from Passmore and Durnin (27).
* Figures obtained for men, caloric cost to be added to basal expenditure.

Strenuous exercise on an irregular basis, in untrained individuals already obese, is obviously not what is advocated here. But a reorganization of one's life to include regular exercise adapted to one's physical potentialities is a justified return to the wisdom of the ages.

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17

ELSWORTH R BUSKIRK
AND DAVID E BASS

Climate and Exercise

SUMMARY

Regulation of body temperature is effected by physiological mechanisms which modify avenues of heat loss or gain, the result is that internal body temperature is maintained within a relatively narrow range in the face of a wide variety of environmental and metabolic stresses Simple exposure to heat results in vasodilatation and sweating Vasodilatation, by increasing skin blood flow, enhances transfer of metabolic heat to the periphery, whence it is dissipated by radiation, convection, conduction, and evaporation Secretion of sweat provides water for evaporative cooling and in moderate to severe heat stress is the body's major defense against overheating Exposure to cold results in vasoconstriction and shivering, vasoconstriction reduces heat loss by reducing heat transfer from the body core to the surface, and shivering increases heat production

Exercise, even in cool environments, imposes a heat load on the body, and evokes the usual physiological regulations against overheating However, thermoregulation during exercise differs from that during simple heat exposure in that the thermostatic 'setting' of the body is set at higher levels, depending on the severity of exercise

When exercise is combined with heat stress, the interactions on the body have important implications, particularly for athletes This arises from the fact that exercise, in addition to imposing an internal heat stress on the body, also has a special requirement for a larger blood flow to the working muscles As a result, even light work in the heat places a large burden on the cardiovascular system to maintain an adequate blood supply simultaneously to the dilated skin blood vessels, the working muscles, and the brain Activity which is easily accomplished in cool weather may become impossible during a hot spell due to the inability of the heart to increase its output sufficiently to meet these three requirements for blood flow, consequently dizziness,

nausea, and other signs of heat exhaustion supervene, and physical performance is markedly impaired To an athlete, this means that an excellent state of physical condition may suddenly become inferior if his athletic event occurs during hot weather to which he is unacclimatized

Of great importance therefore is the phenomenon of acclimatization to heat By working out in a hot room for as little as 2 to 4 hours daily for 7–10 days, an athlete can dramatically improve his ability to function in the heat Performance which might have been reduced as much as 50 percent on the first day in the heat can be improved almost to that attainable in cool weather by this process Once attained acclimatization to heat is well retained for one to two weeks without further heat exposure

Knowledge of the interactions on the body of heat and exercise suggest several practical considerations for coaches and athletes Prior acclimatization to heat is one of the most important Other factors are maintenance of adequate hydration use of lighter uniforms, insuring adequate ventilation for evaporation of sweat scheduling events during the cool hours of the evening in warm latitudes Attention to these simple precautions, based on physiological considerations could lead to improved performance and minimize major form reversals due to hot weather

INTRODUCTION

The human body is constantly bombarded with threats to its equilibrium, these threats come both from within the body and from the environment One of the most common acute stresses arising from within the body is that imposed by exercise On the other hand, the most common outside source of stress is probably climatic e g heat and cold Both these stresses, exercise and climate impose strains on two important physiological parameters, temperature regulation and cardiovascular function In the case of cold stress exercise may serve as an antidote to cold In the case of heat stress, however, one gets at least synergism and probably even potentiation since exercise and heat independently and simultaneously impose strains on both cardiovascular function and temperature regulation

It is the purpose of this chapter to discuss the effects of climate on man s performance ability in exercise and/or athletics, with special emphasis on hot environments It is beyond the scope of this chapter to give a detailed exposition of temperature regulation The reader is referred to the excellent discussion of this topic by DuBois (24), to various chapters in the book edited by Newburgh (43), and the recent book by Burton and Edholm (18)

THE PHYSIOLOGY OF TEMPERATURE REGULATION

Our thermal state is maintained by balancing heat production and heat loss As shown in Fig 17 1, the body can gain heat from metabolic heat pro-

duction and, in hot weather, from the environment The body can lose heat by radiation, convection, conduction, and evaporation of sweat or other water (see definition at end of chapter) Some knowledge of these purely physical factors is required for clear understanding of how body temperature is maintained We shall therefore discuss heat gain and heat loss briefly before considering physiological responses

Normally the major source of body heat gain is from metabolism When a man is relaxed and in the fasting state his Basal Metabolic Rate is such that approximately 70 kilocalories (kcal) are liberated per hour In cool environments this heat production is useful in maintaining normal body temperature, in hot weather it is a physiological disadvantage Under condi

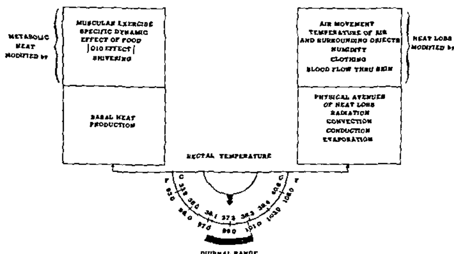


FIG 17 1 *Factors that influence heat balance in man*

tions of heavy exercise, the heat production can exceed 30 times the basal rate, this excess heat is produced mainly in the muscles It is important to realize that the blood which flows through muscles returns directly to the body "core" before being circulated to the periphery When men exercise strenuously, the internal organs are among the first to receive the impact of the increased heat production

The major physical avenues of heat dissipation are radiation, conduction, convection, and evaporation Evaporative heat loss requires some clarification to supplement the definition at the end of this chapter This is the body heat lost when water is converted from liquid to vapor, e g, evaporation of sweat from the skin surface A certain constant amount of water vapor is given off by the body through the intact skin and in expired air, which is almost completely saturated with water vapor This is collectively termed *insensible water loss*, since it is not normally visible; in very cold weather the

familiar foggy breath is evidence of this loss via the lungs, and at minus 40°F the loss through the intact skin is similarly demonstrable as a fog rising from the hands The total insensible water loss is not negligible, amounting to almost one liter of water daily the body heat lost in forming this water vapor amounts to approximately one fourth of the basal heat production This insensible water loss may be disadvantageous in cold weather, since it is not a regulatory mechanism The major source of evaporative heat loss during exercise and in heat stress is from evaporation of actively secreted sweat It should be pointed out that heat loss from all sources occurs at a body surface

In regard to physiological responses, a nude man reclining quietly in a constant temperature room at 85–88°F is in a neutral thermal state, i e, he can remain in the room indefinitely without becoming uncomfortably warm or chilled (55) In a still atmosphere convective heat loss from the skin surface is negligible, since there are no air currents, and conductive loss is small since air is a poor conductor Most of the heat is lost through radiation to the surroundings and evaporation of insensible water Within the body, heat is brought to the surface largely by convection (by the blood flow) and to a certain extent by conduction through the tissues If we now increase the room temperature slightly (to 89°F), certain physiological responses occur At first there is a dilatation of the skin blood vessels, heart rate, and cardiac output increase and blood flow through the skin is increased, as a result there is a higher rate of heat transfer to the skin from the interior This can be seen in the flushed skin on warm days or with severe exercise As a result of this increased skin blood flow, the surface temperature of the body is increased and so is radiative loss to the environment Further increase in ambient temperature imposes a heat load which cannot be met by radiative loss

[illegible]

serve is the elaboration of sweat The sweat glands provide the major physiological defense against overheating The body can secrete over three liters of sweat in an hour of strenuous exercise in hot weather, this represents a very large avenue of heat loss, since the evaporation of each liter of sweat removes approximately 580 kcal from the body It should be emphasized that onl [illegible]

[illegible] the oppressiveness of muggy [illegible] when evaporation is hampered by high humidity In summary, the protective physiological responses to heat stress are increased skin blood flow and the onset of active sweating

If we return the man to a thermally neutral environment and begin to cool the room, certain responses which curtail heat loss occur at surprisingly

high temperatures (we have seen nude men complain of chilliness after two hours at 83°F) First, a constriction of the skin blood vessels occurs, this keeps the warm blood away from the skin surface The skin surface cools gradually with an accompanying reduction in heat loss Actually a slight increase in body core temperature often accompanies this rapid vasoconstriction, since body heat production is now distributed in a smaller volume In addition to the general constriction of skin vessels certain interesting and important localized changes in skin blood flow occur, for example, the blood flow to the fingers and toes is reduced in far greater proportion than in the rest of the body In cold men, the finger blood flow has been found to be reduced to as little as one fortieth of precold values (5), thus transforming the fingers into essentially bloodless masses of tissue Unfortunately, once a man has become chilled it is very difficult to reopen the blood vessels in the fingers short of completely rewarming the individual Since the fingers normally have a very high blood flow relative to their volume, this would appear to be a useful mechanism for reducing total body heat loss, possibly at the expense of freezing fingers

As was the case in heat stress, changes in the size of blood vessels and the vascular bed have only limited protective capacity against chilling As a man becomes progressively colder an important mechanism—shivering—is activated Shivering represents involuntary muscular activity and adds to the metabolic heat production, thereby tending to warm the individual shivering may be manifested as slight tensing of muscles with mild chilling or as violent, uncontrollable spasms when the man is very cold Although even the most violent shivering is not as effective for rewarming as is voluntary exercise, shivering can nevertheless add as much as 350 kcal to the body per hour It has been reported that shivering can prevent further heat loss in a cold man, but will not replace the heat already lost from the body (43)

A comparison of the defenses of the body against heat with those against cold reveals that the first line of defense against both stresses depends on changes in the size of the skin blood vessels and the vascular bed, and that this first line has limited ability to combat heat or cold The major physiological defenses against heat and cold stress are, respectively, sweating and shivering

From the foregoing, it would appear that our body temperature, the familiar 98 6°F, is a jealously guarded constant ' In a sense, however, the term "body temperature' is a misnomer since it obviously is not the temperature of the entire body to which we refer, but that of the body "core" as measured by rectal temperature The body core can be at 99 0°F while portions of the skin surface are at 60°F or lower, even in comfortable environ

97–104°F Since the healthy individual stays within this range in the face of

large fluctuations in heat production and environmental temperature, he is obviously in heat balance, i e heat produced equals heat lost The factors in this balance have been described previously, and we have seen that balance is maintained as a result of physiological responses acting to modify the purely physical avenues of heat gain or loss (Fig 17 1)

The homeostatic mechanisms of the body provide a considerable buffer against undue heat stress For example metabolic heat production during athletic events (especially track) may increase to values more than 30 times the Basal Metabolic Rate without ill effects It is interesting to compare this turnover with the total body heat content Normally the body of a sedentary individual in a comfortable environment contains approximately 2000 kcal (above 0°C) A thirtyfold increase in metabolic rate would add 2100 kcal to the body in one hour thus a well trained athlete can successfully tolerate a *metabolic* heat load which in one hour equals the total heat content (above 0°C) of his body This does not mean that he maintains heat balance during exercise indeed there occurs an actual storage of heat in the body, as evidenced by an increase in body temperature However, sufficient heat is dissipated both during and after the exercise to prevent *excessive* rise in body temperature Most of the heat is lost via evaporation of sweat Sweat rates as high as 3880 grams per hour have been reported for short severe bouts of exercise in hot environments (15) If completely evaporated and sustained for one hour this would extract 2250 kcal, or 32 × basal heat production

Although the body can successfuly tolerate large metabolic heat loads the extent of its success
nisms For example
equally important in l
the skin from which
itself by supporting metabolism of the sweat glands and by providing adequate water for the formation of sweat

The importance of sweat in temperature regulation requires a brief consideration of the physiology of sweating The reader is referred to the excellent recent books by Kuno (36) and by Rothman (49) for detailed accounts

Thermal sweat is secreted by the eccrine glands which are distributed very widely over the body Although the highest concentrations of eccrine glands are on the palms and soles these are responsive to emotional rather than to

cholinergic in nature as evidenced by the fact that drugs which inhibit acetylcholine e g atropine also inhibit sweat secretion

The stimulus for sweating may be emotional or thermal Although emo-

tional (and sensory) sweating contributes little to thermoregulation, it is of importance in certain types of athletics, e g, weight lifting, gymnastics, games involving use of the hands This type of sweating occurs mainly on the palmar surfaces of the hands and plantar surfaces of the feet, the armpits, crotch, and to a certain extent, on the face The stimulus for this type of sweating is largely central in origin and the impulses are confined to central nerve pathways Thermal sweating, on the other hand, may involve both peripheral and central stimuli, and may be reflex or humoral Sudden local heating of the skin can cause sweating via long and/or complex reflexes, the afferent impulse arising from thermal receptors in the skin and ascending via poorly defined pathways to the heat regulatory center in the hypothalamus (17) Whether this mechanism plays a major role in thermoregulation is an open question Another stimulus for thermal sweating is humorally trans ported heat, that is, warm blood from the periphery stimulates the hypotha lamic thermoregulatory centers These centers are also responsive to in creases in skin temperature The relative roles of sensory and humoral stimuli in normal thermoregulation are not clearly understood

Thermal sweating involves a latent period, usually of one two minutes, but occasionally as long as eight minutes (47) Exercise usually shortens this latent period (31) Emotional sweating, however, is almost instantaneous, requiring only the time taken to traverse nerve pathways Thermal stimuli do not ordinarily affect sweat secreted on the palms, soles, pubic region, and axillae and, conversely, emotional stimuli rarely evoke sustained general body sweating

The sweating mechanism is remarkably sensitive In a resting man the critical skin temperature for the initiation of sweating ranges from 31° to 35°C In exercise this is somewhat lower As the heat load increases so does the sweat rate Sweat rate is probably the best indirect index of the heat load imposed on the body, whether from the environment, exercise or a combina tion of both (2 41) (See later section on Heat Stress Indices)

DISTURBANCES OF HEAT REGULATION

When the total heat load on the body exceeds the limit of thermoregu tory compensation, various incapacities occur These fall into three major categories in order of ascending severity heat cramps, heat exhaustion, and *heat stroke (2,38,30)*

The above three categories may overlap or follow each other in sequence Heat cramps and exhaustion are not dangerous if recognized and if the in dividual ceases his activity Heat stroke, fortunately a rare occurrence, can be fatal as a result of irreversible damage to the central nervous system The average individual will "quit" when heat exhaustion sets in, the athlete who is highly motivated, may overextend himself physiologically during contests

TABLE 17 1 Classification of Debilitating Effects of Heat

Disorder	Cause	Symptoms	First Aid
Heat cramps	Excessive loss of salt in sweating	Pain and muscle spasm pupillary constriction with each spasm Body temperature normal or below normal	Rest administer salt and water
Heat exhaustion	Cardiovascular inadequacy dehydration	Giddiness headache fainting rapid and weak pulse vomiting cold pale clammy skin small rise in body temperature	Rest in shade in recumbent position Administer fluids
Heat stroke	Failure of temperature regulatory center due to excessively high body temperature	High body temperature irritability prostration delirium hot dry flushed skin Sweating diminished or absent	Alcohol spray bath or immersion in cold water Medical emergency requiring a physician

in hot weather and thus expose himself to the danger of heat stroke Top physical condition and prior acclimatization to heat (*vide infra*) reduces this risk

THERMOREGULATION DURING EXERCISE

Normally the largest source of heat stress during exercise is that from within the body i e the heat of metabolism Even a completely inactive man has a requirement to lose heat of metabolism at 83°F When severe exercise is undertaken the strain on temperature regulation becomes acute

METABOLIC HEAT DURING EXERCISE

Unfortunately metabolic rate cannot be accurately assessed during the course of an athletic contest using present techniques Body heat gain during exercise has been measured only under laboratory conditions or outdoor trials as a result only limited information has accumulated and "typical metabolic rates for an average individual may be only roughly estimated for some sports

A compilation of walking and running metabolic rates was made by Henry (29) and is reproduced as Fig 17 2 The relationship between speed of progression and the metabolic requirement (Liters of $O_2 \times 5 =$ kcal) indicates approximate heat production Pace for championship performance in the longer track events is listed in the following table

TABLE 17 2 Approximate Pace for Championship Performance in Olympic Track Events

Event			Pace		
Meters	Yards	Miles	Meters/Sec	Yards/Sec	M p h
1,500	1,640	0 93	6 82	7 45	15 2
5 000	5,468	3 11	6 14	6 71	13 8
10,000	10,936	6 21	5 85	6 40	13 1
41,843	45,760	26 00	5 17	5 65	11 6

When the information contained in Fig 17 2 and the above table are com bined and the heat production for a given event estimated, it is readily apparent that running these track events evolves considerable heat within the

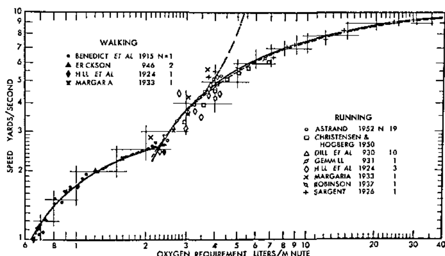


FIG 17 2 *Graphic presentation of basic data on the oxygen requirement of horizontal walking and running (From Henry, 29)*

athlete's body One further consideration is important Since an athlete probably performs long distance events with a mechanical work efficiency of approximately 15 percent, this percentage of total heat production in kcal does not appear as heat within the body Efficiency falls off considerably when work is done anaerobically (with accumulation of an oxygen debt)

A considerable error may be produced by combining data from separate studies, because of large interindividual differences Even 10 or 20 percent less heat elaboration than calculated from Fig 17 2 and Table 17 2 still poses a tremendous heat load which must be dissipated largely by evaporation and convection Bannister s plea prior to the 1956 Olympics becomes meaningful in view of the above I hope the marathon will be held at a sensible time in Melbourne and not in the heat of day

It has been estimated that football requires the expenditure of approximately 800 kcal /one hour contest (25), squash rackets 600 kcal /hour (27), and wrestling 960 kcal /hour (45) Competitive rowing at a rate of 11-12 m p h requires 1230 kcal /hour (28), cross country skiing about 1400 kcal /hour at a speed of 9 m p h (21), and crawl stroke swimming approximately 2000 kcal /hour at a speed of 3 1 m p h (34) More detailed estimations of energy expenditures during athletic activities are available (45 32 42)

FACTORS AFFECTING HEAT LOSS DURING EXERCISE

The avenues of physical heat transfer within the body and at the skin surface are markedly affected by exercise For example, the body movements accompanying exercise or sports enhance heat loss via convection and evaporation as a result of increased air movement over the body surface In this connection it is important to realize that a major part of increased heat production during exercise originates in limb muscles which are close to surfaces which are readily affected by air movement

Muscular activity (with the exception of static muscular activity) usually results in an increased blood flow through the muscles, however, a consequent reduction in blood flow may occur in other parts of the body, e g, splanchnic areas and kidneys (22 35 43 50) The vasomotor, activity, and blood flow response that occurs in a given organ during exercise is dependent on a large number of factors including the ' setting and environment for physical activity, the type of physical activity, the extent of emotional involvement, etc

Heat loss during exercise is markedly affected by what happens at the skin surface The change in skin blood flow may be either an increase, decrease, or no change depending on the degree of vasodilation or of vasoconstriction and the extent of the increase in cardiac output Increased blood flow through the skin would of course facilitate heat loss Ordinarily, measurement of skin temperature during rest provides a rough index of what is happening to skin blood flow During exercise, measurement of skin temperature yields valuable information about the mode of heat loss but provides little information about delivery of heat to the body surface

Fig. 17 3, taken from Hardy, Milhourat, and DuBois (27) shows the effect of exercise on avenues of heat loss and on skin and rectal temperatures

Rectal temperature rose steadily during 36 minutes of a strenuous squash game The skin temperature fell during the same period, the drop in skin temperature was due to a combination of increased air movement over the skin surface and increased evaporation of sweat Skin blood flow may have

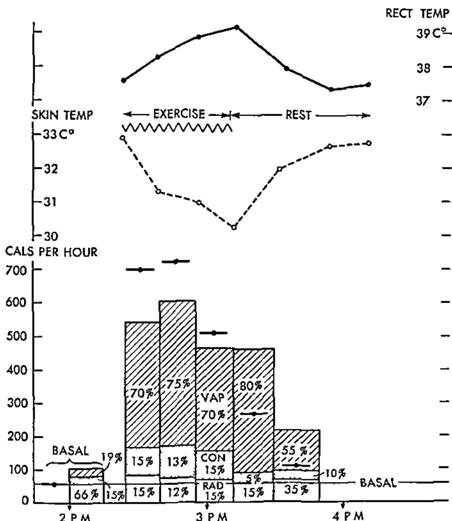


Fig 17 3 *Heat production and heat loss in a man playing squash* (*From Hardy, Milhourat, and DuBois, 27*)

increased but this change was obscured by the substantial cooling of the skin surface

Release of catechol amines (epinephrine and norepinephrine) during periods of emotional stimulation and exercise contribute to the response of the

vascular system to the athletic situation Epinephrine is ' known" as a powerful constrictor of the vascular structures in the skin and splanchnic areas and a vasodilator of muscle vessels while norepinephrine may have little effect on either skin or muscle blood flow (54) Since these hormones are generally released simultaneously in varying absolute and relative amounts (with respect to each other) considerable research is necessary to provide a clear cut picture of the mechanisms of action and sites of action of catecholamines during exercise

INTERNAL BODY TEMPERATURE DURING EXERCISE

It is well recognized that during athletic events, athletes tolerate high body temperatures which would incapacitate a man under conditions of heat stress alone Thus, Robinson found rectal temperatures of 106°F at the end of a three mile race between Gregory Rice and Donald Lash, and no ill effects (43) Although this is an extreme situation, it has been clearly demonstrated that even nonathletes engaging in exercise have elevated core temperatures during the exercise, and that such elevation is apparently beneficial and may be mandatory for optimal performance

In other words the setting of the body's ' thermostat" located in the thermoregulatory centers of the hypothalamus is elevated, with the result that dissipation of the increased metabolic heat during exercise is delayed until the body core has warmed up ' to a level closely related to the exercise level after this has occurred the usual temperature regulatory mechanisms operate as already described Normally, thermostatic settings range from 98°F (sedentary activity) to 104°F, although well trained athletes have wider ranges, viz the examples of Rice and Lash noted above An important feature of this phenomenon, except for very hot environments, is that the increase in body core temperature is a function of work level, and occurs regardless of ambient conditions, unless these conditions become limiting This was admirably demonstrated by Nielsen (44), who showed that when men performed at a fixed work level within the limits of a steady state, they attained the same level of rectal temperature over a wide range of environmental conditions The rectal temperature rose to a peak during the first hour of exercise, with no significant increase thereafter (Fig 17 4)

The foregoing raises two questions (1) Why does an exercising man tolerate increases in body temperature which cause acute distress in non exercising individuals? (2) How does an elevated body temperature enhance performance during exercise?

There are no clear cut answers to these questions, but several factors provide a basis for speculation It is generally recognized that the symptoms of acute heat distress—dizziness, nausea—are the result of decreased cerebral blood supply, due to inadequate cardiovascular function Exposure to heat without exercise is accompanied by a decreased cardiac output (3) and a

respiratory alkalosis (43), either of which can lead to decreased cerebral flow Exercise, on the other hand, gives rise to an increased cardiac output and a metabolic acidosis, with accompanying enhancement of cerebral blood flow It is possible that the greater ability of exercising men to tolerate increases in body temperature is more apparent than real, and that the more meaningful difference may be in ability to maintain adequate cerebral blood flow

Regarding question 2, several physiological advantages may be inferred as

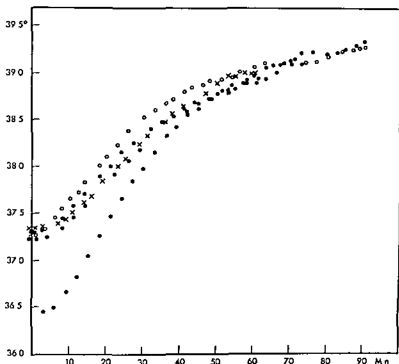


FIG 17 4 *Rectal temperature during heavy work on the bicycle ergometer (1260 Kgm /min)*
• 16°C(61°F) × 11°C(52°F)
36 5 was found after the man
n Nielsen, 44)

a result of elevated body temperatures during exercise For example, the rates of most metabolic reactions are increased with increasing temperature, the dissociation of oxyhemoglobin and oxymyoglobin to provide oxygen for the tissues is similarly enhanced In this connection other factors associated with exercise also increase the release of oxygen to the tissues, e g, acidosis, increased production of carbon dioxide High temperatures would increase rates of diffusion of gases and metabolites to and from the tissues across the interstitial fluid and membrane barriers, and would reduce the viscosity of

the blood and other body fluids All these effects of increased temperature can be predicted to improve performance during exercise, although their relative and total impact have not been adequately assessed Karpovich and Hale recently raised the question whether general "warm up" (elevation in core temperature) will improve performance in most athletic events, since they found no effect on performance in the 440-yard run (33). Others have found either improved performance with "warm up" or an increase in a physiological parameter related to performance, e g, the maximal oxygen intake (4,20,51) Obviously, more research is necessary to clarify the "warm up" issue

HEAT AND EXERCISE

environments Although winter sports would appear, at first glance, to merit consideration of cold-exercise interactions, athletes engaged in such sports are usually warmly clothed and not cold The problem faced by the athlete in the cold is oft

the combination

to clothing leadi

formed with minimal clothing (compatible with adequate protection against the cold) to prevent overheating, as well as to reduce encumbrance to bodily motion

What are the implications to an athlete of performing his sport in a hot

stress

When an individual is abruptly exposed to heat and remains inactive, the normal thermoregulatory mechanisms—peripheral vasodilatation and sweating—are adequate to prevent overheating in the face of a large en

ficiently great to become meaningful in an inactive man until many hours have passed In summary, sedentary activity is well tolerated in the heat

If the individual is required to exercise moderately, e g, walk at 4 m p h,

ness or faintness For example, Bass, *et al* (11) found pulse rates as high as

186 in men who walked for the first time at 4 m p h at 120°F, 18 percent R H, although the same walk at 77°F resulted in rates of 115–120 Exercise in the heat involves two stresses each with a different requirement for blood flow In an unacclimatized man, the heart cannot meet both demands adequately, as a result, to paraphrase a colloquialism, something must "give" Probably everything "gives' to a certain extent, but the well known defense against shock—fainting—usually supervenes to halt what could be a dangerous situation In other words, an unacclimatized man trying to do work in the heat suffers from incipient circulatory shock, qualitatively similar to what he would suffer if he had hemorrhaged

In addition to and probably as a result of cardiovascular inadequacy, temperature regulation suffers appreciably, since impaired blood flow also means impaired heat transfer from the body core to the skin, hyperthermia becomes a distinct danger As was pointed out earlier, well motivated athletes who ignore warning signs of dizziness and faintness may actually become victims of heat stroke because of this vicious circle A further complication is that the profuse sweat production during work in the heat, so

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and skin temperatures, high pulse rates, dizziness, nausea, etc —are dramatically reduced by repeated daily exposures to work in the heat This is the result of acclimatization to heat, a phenomenon of great importance to athletes *This is discussed in detail in the following section*

ACCLIMATIZATION TO HEAT

When a sudden onset of warm weather occurs, or an athletic event is scheduled for a warm climate, it is common coaching experience to observe an impairment in performance ability Tasks that were easily performed in cool weather become much more difficult If the warm weather persists, or the team resides and works out in the warm climate for several days, performance ability gradually returns and 'acclimatization" to heat is said to have occurred Several physiological changes are associated with acclimatization to heat (11,13)

An athlete acclimatized to heat is able to work with a lower body temperature, a lower heart rate, and a more stable blood pressure than when not acclimatized, since more precise heat regulation occurs largely as a result of cardiovascular adjustments and a slight increase in sweat production In addition, he should perform with a decreased metabolic cost (i e, greater efficiency) unless his event requires severe effort With regard to the latter, betterment of cardiovascular function and sweating enable the athlete to perform more work in a given warm climate and extend the upper range of

outdoor temperature and humidity than he can tolerate in a given period of time

In general acclimatization to heat may be characterized by the following summary

1 It begins with the first exposure progresses rapidly, and is well developed in four seven days
2 It can be induced by short intermittent exercise periods in the heat e g two-four hours daily Inactivity in the heat results in but slight acclimatization
3 Subjects in good physical condition acclimatize more rapidly and are capable of more work in the heat Tiptop physical condition does not confer automatic acclimatization
4 The ability to perform maximal work in the heat is attained quickly by progressively increasing the daily work load Strenuous exertion on first exposure may result in disability that will impair performance for several days Care should be taken to stay within the capacity of the athlete until acclimatization is well advanced
5 Acclimatization to severe conditions will facilitate performance at lesser conditions
6 The general pattern of acclimatization is the same for short, severe exertion as for moderate work of longer duration
7 Acclimatization to hot dry climates increases performance ability in hot wet climates and vice versa
8 Inadequate water and salt replacement can retard the acclimatization process (52)
9 Acclimatization to heat is well retained during periods of no exposure for about two weeks thereafter it is lost at a rate that varies among individuals Most people lose a major portion of acclimatization in two months Those who stay in good physical condition retain their acclimatization best
10 If it is desirable to retain acclimatization, periodic exposures at two-week intervals would be best

The physiological adaptations underlying heat acclimatization are complex and not clearly understood Changes in adrenocortical activity (9), in

cardiovascular function as acclimatization progresses

sonably hot spell or in a hot climate, the team or individual who has had the

foresight to become acclimatized to heat suddenly becomes superior, as a result the acclimatized have a disproportionately greater chance of winning and what the gambler would term "form upsets" result For example, many people will remember the 'Sugar" Ray Robinson–Joey Maxim fight of 1952 Robinson was apparently ahead on points until the effects of the hot humid atmosphere began to take their toll Since Robinson had been much more active than Maxim during the early stages, the greater work load, plus the heat stress, reduced Robinson to such a helpless state that he was unable to respond to the bell at the 15th round, and Maxim won by a technical knockout

In the 1956 Olympic Games, the marathon was run in humid 85°F air It was not surprising to hear that the race was won by a French Algerian (Alain Mimoun) who routinely trained in the heat At the start of the Olympic Marathon, one of our own marathoners, Dean Thackery, reported that Emil Zatopek, the famed long distance runner, summarized his chances in light of the weather with the resigned statement, 'Today we die!"

In December 1956, the outstanding schoolboy football team in Massachusetts journeyed to Florida to play the best schoolboy team in that area Since the game was a postseason game, the Massachusetts boys were not heat acclimatized The game was played in humid 70°F+ air in a large stadium where the radiation load was high and air movement low The game was played on even terms until the latter part of the third and the fourth quarter, then the southern team literally romped away from the northerners Romps of this sort occur despite the weather, but the question can legitimately be asked how frequently and to what extent weather affects the outcome of athletic events

Although reliable statistics are not available, it appears that weather frequently benefits the prepared, and severely handicaps those who are not

WATER AS A SPECIAL ATHLETIC ENVIRONMENT

Swimming poses a special heat regulation problem since evaporative heat loss (excepting water vapor loss via lungs) is curtailed and most body cooling must occur by convection and conduction

The temperature range of pool water for competitive events is not standardized and has been found to vary between 68–90°F This range results both from "expressed" individual preference on the part of swimmers and coaches and from limitations imposed by water conditioning facilities A careful investigation of the influence of pool water temperature to swimming performance was recently made (1) Optimal performance for the 50 yard dash was obtained in water at temperatures between 84–94°F whereas an endurance swim (1500 meter) was best performed in water between 74–79°F. As the pool water temperature approached that of body temperature, performance in the 1500-meter event deteriorated In this instance, terminal

rectal temperatures averaged 103 5 when the pool water was 94°F It is quite possible that the large volume of blood in the skin necessary for conductive and convective cooling partially depleted the blood supply available to working muscles and performance fell off as a result In the shorter events, improved performance in warm water is probably associated with an optimal "core" temperature for peak performance ("warm up").

If the water is near freezing, 0°C (32°F), mere survival becomes a problem because of large convective and conductive loss The channel swimmer who "thrives' in water near this temperature is usually an individual of rotund body build who possesses a large amount of subcutaneous and total body fat (supplemented with a thin layer of grease applied to the body surface) This type of individual also has a smaller surface area in relation to body mass than the typical sprint swimmer The well padded channel swimmer is therefore well insulated when cutaneous blood flow is diminished in cold water, and can usually finish a swim with little or no fall in rectal temperature A lean swimmer would probably be hard pressed to survive more than an hour or two under conditions such as exist in the Strait of Juan de Fuca (40–60°F water) unless heat production balanced or nearly balanced heat loss throughout the swim Various investigators have been interested in body cooling in water with the subjects active and nonactive (46 14 26), but considerable work still remains to be done in order to clarify individual differences in heat exchange at different water temperatures

DEHYDRATION, WATER, AND SALT

Important aspects of dehydration will be discussed in the chapter on body fluids, however, certain practical information is pertinent in a chapter on heat exchange Dehydration should be considered a potential source of debilitation in any events where considerable body sweat is elaborated Foot ball and basketball players may lose from 3–7 percent of their body weight during the course of a contest In this situation, a larger proportionate loss is sustained by the plasma volume than by other compartments of body fluid (2) Because of this unequal loss circulation to working muscle and to the skin is curtailed, which in turn leads to deterioration in performance It would seem wise, in the absence of contradictory information, to replace body fluid losses at least to the extent of limiting dehydration to no more than 2–3 percent of body weight (37)

Salt is lost in relatively large amounts in sweat, hence, the individual daily requirement may be increased by 5–10 grams under conditions where large amounts of sweat are lost per day Usually an extra requirement can be met by a few hearty shakes of salt with each meal The use of enteric coated salt tablets will serve the same purpose, but cases of gastrointestinal upset frequently occur, because concentrated salt irritates the mucosa lining of the gastrointestinal tract Cachets or salt containing dough balls (unleavened bread) have been used with some success for experimental purposes Salt

solutions of 0 1–0 2 percent concentration may also be used Certain athletes prefer to use bouillon (Oxo) preparations Although any of the above will provide the necessary extra salt, it is the experience of most investigators that there is no better method of obtaining salt than by merely salting one's food liberally

INDIVIDUAL DIFFERENCES

A certain number of individuals can be labeled as heat intolerant In terms of heat acclimatization, this means that these people will not readily acclimatize to heat or will only partially acclimatize after numerous exposures Malfunction of the sweating mechanism or thermoregulatory centers is usually associated with heat intolerance Fortunately, the number of people who are heat intolerant is only of the order of 1 percent (57) Of the normal' 99 percent, a considerable range in tolerance exists which is dependent on physical conditioning body size, build, and composition

Kuno (36) has investigated racial differences and place of birth in relation to the number of functioning sweat glands per unit surface area He concludes from his limited data that the person exposed to hot conditions at an early age, irrespective of race, develops more sweat glands and is therefore more capable of withstanding heat later in life This observation should be corroborated by studies conducted on a larger scale, because it does have important implications in terms of work performance in the heat

The large, fat man is at a distinct disadvantage in the heat, but has some advantage in the cold (6,7,39) The large, fat man has a smaller surface area for the evaporation of sweat per unit mass of heat producing tissue than his thin counterpart (48) and also possesses more insulation (subcutaneous fat) as a barrier to conductive heat transfer Thus the fatter the man the lower his resistance to heat stress We have already indicated that channel swimmers tend to be large and somewhat obese individuals Pugh *et al* (46) recently examined the rate of cooling of men immersed in water, and found that the major proportion of interindividual differences appeared to be related to the thickness of subcutaneous fat Similar findings have been reported for men exposed to cold air (42) Mean skin temperature drops more rapidly in the fat man on exposure to cold and remains at a lower level, while rectal temperature remains at a higher level in the fat than in the thin man This means that when blood flow through the skin is reduced, peripheral insulation is greater in the fat than in the thin man Thus the typical channel swimmer loses less heat to the cold water and consequently can maintain heat balance at a lower metabolic rate than the thin man

CLOTHING AND EQUIPMENT

Clothing is a necessity in the cold for the inactive man, because of obvious insulation requirements An athlete engaged in a strenuous winter sport

such as cross country skiing needs little clothing, because of his high heat production In the heat, clothing fulfills different functions, it provides protection against radiant and convective heat gain from the environment, but acts as a partial vapor barrier and may, depending on design, material, characteristics and fit, change the effective surface for evaporative cooling Generally, the higher the vapor pressure the less clothing should be worn Clothing that permits considerable ventilation and is vapor permeable would appear to be desirable

Clothing worn during athletic contests staged in warm weather may reflect tradition or current fashion and contribute no more than added encumbrance Recent trends toward functional sport clothing are commendable, comfort has been the criterion for this development

Specialized equipment, such as that worn in football, has not been designed with heat stress in mind Many of the items of football armor, i e, shoulder pads rib pads hip pads etc cover areas of the body where considerable evaporative heat loss normally occurs Since these items are relatively vapor impermeable they impose a formidable barrier for evaporative cooling This barrier is supplemented by helmet, jerseys, pants stockings shoes and other items In addition these items promote a higher level of metabolic activity, because their weight adds to the player s work load It is not surprising that football players may lose from 5–15 pounds of body weight during the course of a game played on a warm day

Over the years several improvements in football gear have been made from the standpoint of improved performance in the heat, certain items of equipment have been lightened and the body surface area covered by clothing has been reduced (sleeveless jerseys) Use of fabrics which are more permeable to water vapor would be another step forward

HEAT STRESS INDICES

The physical components of heat stress have been examined extensively by physicists physiologists and psychologists, and in many instances the magnitude of the environmental heat load in terms of expected physiological strain can be determined Thus far two approaches have been taken in formulating a heat strain index (1) on the basis of the environment alone and (2) on the basis of the man environment interaction

In athletics it is more desirable to talk about the latter, since the metabolic rate in most competitive athletics is high and therefore a major consideration in any heat stress index The efforts of McArdle, *et al* (41), Belding and Hatch (15), Blockley, *et al* (16), and Lee (40) are noteworthy in this regard

In 1947, McArdle, *et al* (41) formulated a Sweat Rate Index which has been used mainly by British physiologists, who have demonstrated its superiority to previous indices over a wide range of heat stresses In essence

this index is a prediction of sweat rate from ambient weather information plus the metabolic rate of the man It has been found that predicted four hour sweat rate (P4SR) agrees well with actual sweat rate at least under laboratory conditions Although this index was formulated from empirical data, it does have the advantage of indicating stress in physiological terms, but has the disadvantage in that it applies only to work loads that are much less than those experienced in most competitive athletics

Recently, attempts have been made to predict physiological heat load of the working man in a given environment from theoretical considerations Woodcock (56) devised a theoretical model based on physical laws, which

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TABLE 17 3 Approximate Limiting Conditions for a Well Conditioned, Heat Acclimatized Athlete Performing One Hour of Sustained Running

D B (Dry Bulb)	W B (Wet Bulb)	R H (Relative Humidity)	V P (Vapor Pressure)
°F	°F	%	mm Hg
82	82	100	27
83	80	76	25
90	77	55	20
92	73	37	15
96	69	25	11

environment except radiation, and include the effect of metabolism Belding and Hatch (15) have produced a nomogram for securing a Heat Strain Index (HST) Radiation, as measured by a black globe thermometer, is included in this index Blockley, *et al* (16) have undertaken the most comprehensive analysis of heat stress and have termed it a *biothermal analysis system* Their data in terms of time tolerance curves may become extremely useful Although these theories require the experimental validation which is currently in progress, they represent an important avenue of approach to the heat stress problem The original sources should be consulted for a further discussion of these indices

Although the various indices differ in approach, they tend to give similar answers to the question, How long can a man work at a given rate in a given environment?'

Table 17 3 has been prepared as a rough guide for heat tolerance in composite form from the indices referred to above These limits should be regarded as approximations for a well conditioned, heat acclimatized runner The runner is working at a rate of 1080 kcal /hr at a work efficiency of 15

percent for one hour Radiation is assumed negligible and the effective air movement is 10 m p h *Clothing consists of shorts and track shoes*

The approximate limits listed would be altered by individual differences in conditioning training for the event acclimatization to heat, body build and body composition Changes in air movement effective radiation, clothing etc would also alter the estimated limits of tolerance

Table 17-3 emphasizes the important role of the absolute humidity in limiting performance When the vapor pressure of the environment is close to that of the skin (42 mm Hg) evaporative heat loss is drastically curtailed unless air movement is exceptionally high Thus wet bulb temperature as a single parameter may be particularly indicative of the thermal strain imposed by the environment providing the radiant load is low Wet bulbs over 70°F should be viewed as close to the tolerance limit for a competitive athletic event involving severe work Wet bulbs of 80–82°F will indicate tolerance limits for most athletic activities with the possible exception of the relatively inactive sports such as baseball

WEATHER INFORMATION

Weather data are accumulated daily throughout the United States and it is easy to obtain probable information for a certain locale Coaches commonly rely on their own weather experience in a given area and pay little

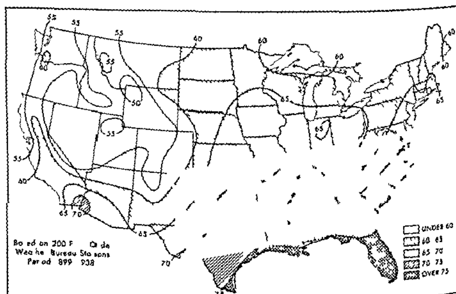


Fig 17 5 *Average July wet bulb temperatures (°F) in the United States (From Visher 53)*

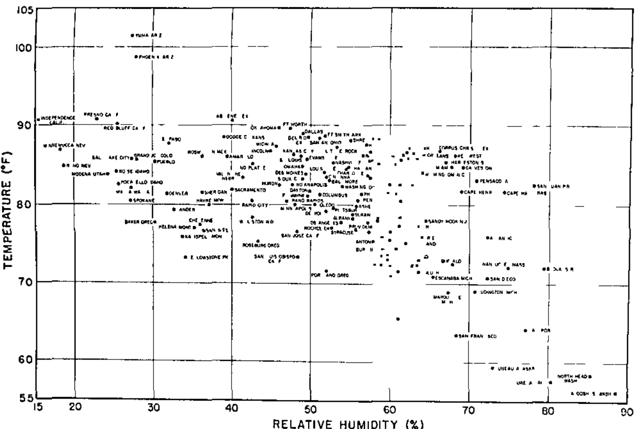


Fig 17 6 Average values of local noon temperature and relative humidity for the month of July, 1918–1938, in the United States (From Day, 23)

attention to weather information which is much more comprehensive a consequently a better guide for athletic planning Guidance may not be important for acclimatized individuals residing in a hot area and who e pirically know how to pa themselves, but it is essential planning competitive trips for unacclimatized and uninitiat Examples of the type of guidar that is available are given below

Weather experience (Dry Bu and Wet Bulb) for July in th United States for the period 191 1938 is shown in Fig 17 5 and Fi 17 6 (53,23) In terms of limitir conditions (Table 17 3) one ca see that sports which require re atively high levels of energy e penditure for prolonged period should probably not be schedule for unacclimatized men during th heat of the day in areas south o the 70°F Wet Bulb isobar (Fig 17 5) These plots show average values and do not show the fre quency of occurrence of days dur ing July with wet bulb over 90°F Knowledge about the most severe conditions that may be encoun tered would also be of value This information is also available from the United States Weather Bu reau

Fortunately common sense

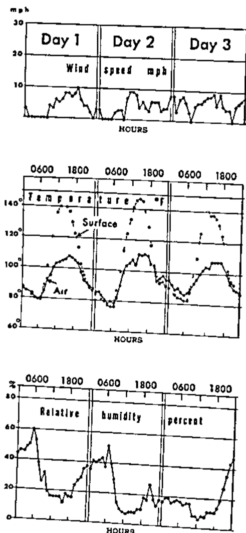


FIG 17 7 *Three days of summer weather at Yuma test station Arizona*

physical activity is usually gauged to the environment and athletic contests are ordinarily scheduled for the evening hours Considerable benefit may be gained by evening scheduling as shown in Fig 17 7, which depicts diurnal variation in summer weather in Yuma, Arizona The exuberant, unacclimatized outsider frequently pays by way of poor performance or heat disability unless he is competently advised

DEFINITIONS

RADIATION Exchange of heat between objects It depends solely on the surface temperature and the characteristics of the surface

CONDUCTION Transfer of heat between objects in physical contact

CONVECTION Exchange of heat between an object and the streaming currents of gas or liquid flowing past the object

EVAPORATIVE HEAT
the vapor state (1

METABOLIC RATE
actions It is usually calculated indirectly from the consumption of oxygen (Indirect calorimetry)

KILOGRAM CALORIE (kcal) The amount of heat required to raise the temperature of 1 kilogram of water from 15 to 16°C

DRY BULB (D B) Temperature recorded by an ordinary mercury in glass thermometer whose bulb is kept dry

WET BULB (W B) Temperature recorded by a similar thermometer with a wet wick over the bulb exposed to a current of air moving at least 1000 feet/minute When D B = W B, the air is said to be saturated and the relative humidity equals 100 percent

ABSOLUTE HUMIDITY The concentration of water vapor in air

RELATIVE HUMIDITY The ratio, expressed as percent, of the amount of water vapor in the air to the amount that the air could hold at the same temperature if saturated times 100

BODY "CORE" The central portion of the body which, for purposes of assessing heat exchange, is assumed to be at a constant temperature Rectal temperature is usually taken as a measure of "core" temperature

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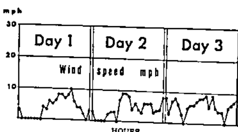
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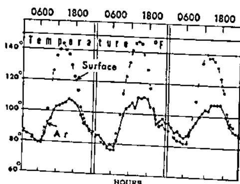
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9 Barcroft, J, Benger, C A, Bock, A V, Doggert, J H, Forbes, H S, Har-

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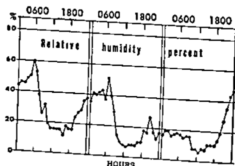


FIG 17 7 *Three days of summer weather at Yuma test station Arizona*

Fortunately common sense [illegible] physical activity is usually gauged to the environment and athletic contests are ordinarily scheduled for the evening hours Considerable benefit may be gained by evening sched uling as shown in Fig 17 7, which depicts diurnal variation in summer weather in Yuma, Arizona The exuberant, unacclimatized outsider fre quently pays by way of poor performance or heat disability unless he is com petently advised

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CONVECTION Exchange of heat between an object and the streaming currents of gas or liquid flowing past the object

EVAPORATIVE HEAT LOSS Heat necessary to change water from the liquid to the vapor state (1 gm H_2O requires 0 58 kcal at 33°C)

METABOLIC RATE Heat produced within the body associated with chemical reactions It is usually calculated indirectly from the consumption of oxygen (Indirect calorimetry)

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18

BRUNO BALKE

Work Capacity at Altitude

SUMMARY

The problem of alterations in physical performance or work capacity at higher altitudes normally will not be recognized unless preparations become necessary for sportive events at locations situated well above sea level, or unless recreative or competitive activities such as climbing or skiing are planned in high mountainous areas

In ascending to higher altitudes the decrease in total barometric pressure results in a decrease of the partial oxygen pressure The latter mainly deter

culatory and respiratory adaptations are normally encroached upon to a maximal extent, this inadequate oxygen supply must result in a reduction of working capacity Thus, impairment of physical performance was found measurably reduced at altitudes of 10,000 feet and more

tain slopes at altitudes which are fatal to normal individuals even during rest

The following chapter presents results of recent studies on human work capacity before, during and after altitude acclimatization and discusses some of the physiological aspects involved

Finally, some implications of altitude for athletic competition are made (1) Athletic competition at higher altitudes Performance involving sudden

bursts of muscular strength or speed, such as sprints, which are accomplished anaerobically will not be affected by higher altitudes, however complete recovery requiring repayment of the oxygen debt, will take longer at altitude than at sea level Performance extending over a period of more than about one minute is affected by higher altitudes unless an adequate period of acclimatization has been undergone Soon after arrival at higher altitude, changes occurring in the blood will seriously interfere with performance, and it is therefore desirable to perform as soon as possible after reaching altitude if an adequate acclimatization period is not permitted (2) Effects of physical training at altitude Altitude acclimatization and physical training at altitude bring about physiological changes which should improve endurance performance—as for example, in the mile run

The attempts to climb the highest mountains on earth, the contact with the inhabitants of high mountainous regions, and the development of aviation have introduced new problems in physiology *Altitude physiology* as a new branch of science contributes in many ways to the knowledge of the adaptabilities and the limitations of human life

Probably for the first time in history the deadly lack of oxygen in the upper atmosphere was realized in 1875 in France when a free balloon with 3 crew members on board the gondola reached a maximal altitude of approximately 28,000 feet Only one of the aeronauts, Gaston Tissandier, survived this episode He also had been unconscious for an unknown length of time (2)

On the other hand there are several men who in the Himalayan Mountains climbed to altitudes above 28,000 feet without the use of oxygen equipment and returned alive Nothing could better demonstrate the enormous capacity of the human organism for adaptations to 'abnormal' living conditions

Systematic studies of the effects of altitude and altitude acclimatization on

increasing interest in aviation medicine a great deal of experimental work was transferred from the rugged mountain slopes of the Alps (6,8), the Rocky Mountains (3), and of the Andes (1) into the more readily accessible low pressure chamber There the problem of hypoxia, or reduced oxygen tension was thoroughly studied, proper oxygen equipment was developed and tested and the limitations of man for high altitudes were established It was found that people normally living close to sea level become critically hypoxic at an average altitude of 25 000 feet By sufficient length of acclimatization to low barometric pressures an altitude of 33 000 feet can be tolerated for a few minutes before becoming unconscious

The physiological manifestations of the acclimatization process are manifold and include changes in respiration, in circulation, in blood characteristics, in the biochemistry of the tissue fluids and cells, etc The most remarkable evidence of the effects of natural acclimatization must be seen in the capacity for strenuous physical work at high altitude E F Norton, a member of the British Mt Everest expedition in 1924, climbing without the benefit of oxygen equipment, reached an altitude of 28,126 feet He only turned back because the remaining daylight did not permit climbing the last 800 or 900 feet and then returning in safety Although he confessed having been near the end of his powers, he still believed that "the atmospheric conditions between 28,000 and 29,000 feet would not prevent a fresh and fit party *from reaching the top of Mt Everest (29,000 feet) without* oxygen" (7)

There is, of course, a significant reduction of work capacity at higher altitudes, compared to an individual s work capacity near sea level This reduction is measurable already at an altitude of 10,000 feet Work tolerance at 14,000 feet is approximately 75 percent of normal performance One could assume that people who are living permanently in high mountainous regions and have become "normal in every respect of life should have regained what we may call a normal level of work capacity According to Hurtado, who directs the Andean Institute of Biology in Lima, Peru, the physical performance of native residents at Morococha (14,800 feet) not only equaled but surpassed that of comparable subjects tested near sea level (4) In running on a treadmill at the same speed and grade to exhaustion *the natives in the high altitude laboratory were able to tolerate work for a* longer period of time And this was done, as Hurtado found, with less oxygen consumption and with an only slightly increased pulmonary ventilation From these findings the conclusion was drawn that working efficiency of the altitude residents is higher than of the sea level subjects

These fascinating results are not duplicated if one studies the work capacity of man after temporary acclimatization to high altitude In recent experimental investigations six individuals were tested for work tolerance after they had been acclimatized for a period of 6 weeks to an altitude of 14,160 feet [illegible] iza tion [illegible] ells and [illegible] ood pressure to normal values Table 18 1 presents some of the maximal functional data at the termination point of a standard test procedure on a treadmill or bicycle ergometer at sea level and at the altitude of 14,160 feet after the acclimatization period In the right hand column of this table are shown the normal values of the functional response to the work load being terminal in the altitude experiments In all instances the tests were carried out to the same point of subjective as well as objective limitations of cardiovascular and/or respiratory nature

The data suggest that the limiting factor of work at altitude must be seen in the engagement of the maximal breathing capacity at a lower work load level Circulatory and biochemical functions are, at this point, still below their normal maximum

Table 18 2 demonstrates how the pulmonary ventilation would have to increase for various grades of energy metabolism at various altitudes It can easily be seen that at very high altitudes even 'moderate' work with an

TABLE 18 1 Functional Data of Work Capacity Tests at Sea Level and at Altitude[a]

	At Sea Level	At 14 000 Feet	At Sea Level[b]
Work intensity in mkg /min	1500	1130	1130
Oxygen intake in ml /min	3500	2700	2700
Pulse rate per min	186	163	156
Systolic pressure in mm Hg	183	178	173
Diastolic pressure in mm Hg	68	82	67
Ventilation (BTPS) in l /min	110	132	70
Blood lactic acid in mg /100 ml	100	71	40
Oxygen carrying capacity in vol %	20 4	23 5	20 4

[a] Mean values of six subjects tested
[b] *Normal functional response to the work intensity being maximal at altitude*

ing or, with the same respiratory effort a larger volume of air will pass the lungs (3) Physical activity with the increased demand for breathing at altitude involves a very effective training of the respiratory muscles and results in a greater maximal breathing capacity during work While at sea level the usually observed maximal values of ventilation amount to approximately 120 liters per minute (BTPS), values of 160 to 180 liters/minute

less normal breathing capacity during work was re-established after several weeks of living close to sea level

Table 18 2 The Pulmonary Ventilation (BTPS) for Given Metabolic Rates at Various Levels of Altitude

Oxygen intake, ml /min	1000	1480	1950	2400	2800	3100	3400	3700	4000[a]
Ventilation (STPD), l /min	20	30	40	50	60	70	*80*	*90*	*100*[a]
Ventilation (BTPS), l /min									
at sea level, B = 750 mm Hg	*24 6*	*37 0*	*49 4*	*61 7*	*74 0*	*86 4*	*98 7*	*111*	*123*[a]
at 10,000 feet, B = 523 mm Hg	36 2	54 3	72 4	90 5	109	127	145	163	181
at 14,000 feet, B = 447 mm Hg	43 2	64 7	86 2	108	129	151	173	(194)	—[a]
at 18,000 feet, B = 379 mm Hg	52 0	77 0	104	130	156	182	(208)	—	—
at 21,000 feet, B = 335 mm Hg	60 0	89 8	120	150	180	(210)	—	—	—
at 24,000 feet, B = 294 mm Hg	69 8	105	140	175	(209)	—	—	—	—
at 27 000 feet, B = 258 mm Hg	81 8	123	163	(204)	—	—	—	—	—

[a] Figures derived from experimental results of two subjects

Table 18 3 Critical Data of Physical Performance Tests at Sea Level and at Altitude[a]

	Test Duration Min	Oxygen Consumption ml /min	Pulse Rate /min	Blood Pressure Syst mm Hg	Blood Pressure Diast mm Hg	Ventilation BTPS l /min	Ventilation STPD l /min
Sea level	24 5	4000	183	190	70	121	98
14,160 feet, nonacclimatized	19	2800	172	192	62	128	59
14,160 feet, acclimatized	20	3250	158	194	84	161	76
Sea level, 2 weeks after return	27	4350	188	190	64	141	114
Sea level, 8 weeks after return	25	4150	186	192	70	125	101

[a] *Mean values of 2 subjects displaying almost identical work tolerance*

The prolonged effect of altitude training upon the capacity for breathing is one of the factors contributing to the very interesting observation that physical performance is increased after return from altitude to normal atmospheric conditions, compared with the original controls This improvement lasts for a few days, slowly diminishes, and is as good as lost after about eight weeks Table 18 3, by presenting respiratory and circulatory maxima obtained during performance tests of two well trained individuals, demonstrates the changes in functional adaptability resulting from acclimatization to and de climatization from altitude

The expeditions to the highest peaks of the Himalayan and Andean Mountains have shown that the physical performance of the native porters, chronically acclimatized to high altitude, was not superior to that of the mountaineers who were acclimatized for only a relatively short period of time Recently, in addition to the Mt Evans studies, comparative investigations of work capacity were made at Morococha (14,800 feet) in Peru on chronically acclimatized Indian natives and more acutely acclimatized newcomers The results are presented in the following (1) There was no marked difference in the actual work capacity of both groups (2) The oxygen intake for the same work intensity, measured during treadmill work, was in both groups identical relative to their mean body weights (3) Although no distinctive difference in pulse frequency was observed, the pulse pressure of the natives was lower throughout (4) The pulmonary ventilation of the natives followed almost the pattern observed in work capacity tests of individuals tested under normal atmospheric conditions and amounted to only half the ventilation of the newcomers at each work load level

These results suggest that the efficiency for physical work, in general, is identical in temporarily and chronically acclimatized man The latter, however, displays a trend toward a better working economy where saving of energy is possible—namely in the work involved in pulmonary ventilation That is accomplished by a higher extraction of oxygen from the inspired air and by returning a higher percentage of [illegible] red air

fore appear to be less sensitive to the appropriate stimuli than the respiratory centers of the temporarily acclimatized individual This change of sensitivity becomes more pronounced in the so called 'Soroche" or "chronic mountain sickness" which occasionally occurs as an abnormal overcompensation of the adaptive mechanisms to chronic hypoxia Under the conditions of this disease a *hypo*ventilation develops Neither increased oxygen lack nor increased carbon dioxide tensions are able to stimulate ventilation substantially. Natives displaying the symptoms of chronic mountain sickness are able to hold their breath for a surprisingly long period of time

The effects of physical training, stressing maximal adaptations of circulatory and respiratory functions, are to a certain extent comparable to those of altitude acclimatization In both cases the organism is striving for economy: the ventilation equivalent for oxygen (pulmonary ventilation in l/min per 1000 ml of oxygen taken up) becomes reduced If the same amount of oxygen has to be supplied with a reduced respiratory volume it can be achieved only by a higher oxygen extraction rate of the inspired air Also, during physical training as well as during altitude acclimatization a relative bradycardia develops That means that for any given metabolic rate more oxygen is supplied to the working tissue with one pulse beat The increase of this so-called "oxygen pulse" can be effected by two factors either by an augmentation of the stroke volume of the heart or by an increased oxygen extraction from the blood, resulting in a higher arteriovenous difference of oxygen in the blood It is still unknown which of the two factors might become more effective because research in this field is suffering under the lack of methods to measure adequately and routinely the cardiac output during severe work and the distribution of blood to the various organs

There is an important difference in the adaptive state of the blood at a given altitude between chronically and temporarily acclimatized man In the natives, permanently living at high altitude, red blood cells and hemoglobin are increased to such an extent that the low oxygen saturation of the blood at this altitude is completely compensated for, the blood carrying now as much oxygen as in normal individuals under sea level conditions Such a complete acclimatization of the blood is rarely achieved by "newcomers" and is a matter of many years It was shown, however, by Luft (5) in observations on climbers in the Himalayan Mountains, that the sea level values of oxyhemoglobin were regained for any given altitude when the climbers had spent several days at altitudes approximately 3000 to 5000 feet higher Thus complete adaptation of the blood was obtained for an altitude of 10,000 feet after approximately 2 weeks at 13,500 feet, for 14,000 feet after further 2 to 3 weeks at 19,000 feet, for 17,000 feet after 3 to 4 more weeks at 22,000 feet, and, finally, to 19,000 feet after a further stay of 2 weeks at an altitude of 22,000 feet At the peak of acclimatization the average values of five mountaineers for their blood were approximately 8 millions of red blood cells per unit and 24 5 g percent of hemoglobin (compared to normals of 5 millions and 16 g percent respectively) Therefore the oxyhemoglobin at 19,000 to 20,000 feet of altitude, or at about 65 percent of oxygen saturation of the blood, amounted to approximately 21 5 Vol percent or 9 5 mMol/1 —a normal sea level value In this state of altitude acclimatization physical work capacity was considered "normal" by the individuals at altitudes of 14,000 to 17,000 feet Systematic studies of work capacity at lower levels of altitude after acclimatization to higher altitude have not been made, however It would certainly be of interest to know the highest level

of altitude at which work capacity could become "normal" after maximal physiological acclimatization to altitude is achieved

ALTITUDE IN RELATION TO ATHLETIC COMPETITION

It might be of some interest to consider the implications on performance deriving from athletic competitions at higher altitudes, or the implications of a physical training at higher altitudes upon the performance capacity after return to sea level

Athletic Competition at Higher Altitudes

Any type of work calling for sudden bursts of muscular strength or speed, including sprints over 100 to 220 yards or of course all technical events of still shorter duration of time, will not be affected by the lowered atmospheric oxygen pressure These types of activities do not require optimal circulatory and respiratory adaptations and are usually performed "anaerobically" by utilizing the individual's capacity for incurring oxygen debts Since the oxygen debt has to be repaid during a recovery phase, the respiratory and circulatory efforts during the recovery phase will be intensified at altitude Complete recovery from even short "bouts" of physical activity will require a longer period of time than at sea level

All activities which consist of intermittent or extended bursts of muscular efforts over periods longer than about one minute are affected by higher altitudes because of the compensatory demands on the circulatory and respiratory functions An adequate period of acclimatization to altitude would become necessary to restore the "normal" performance capacity. As a rule of thumb, a minimal time of one week is required for acclimatizing to an increase of altitude in the order of 3000 feet If an adequate time for the training at altitude is not permissible, the stay at altitude before the competitive event should be made as short as possible Soon after the arrival at higher altitude the blood will undergo acid base changes which will seriously interfere with maximal performance

Effects of Physical Training at Altitude

Altitude acclimatization, enhanced by physical training at altitude, results in an increase of hemoglobin and in an augmentation of the total blood volume, in improved maximal breathing capacity, and possibly in increased vascularization of lung and muscle tissue Performance capacity therefore should improve beyond the point which can be achieved by training under normal atmospheric pressure After an adequate training at altitudes between 7000 to 10,000 feet an athlete should be able to run the mile in less than 4 minutes if he had come very close to the 4 minute mile by the previous training Additional experimental studies should be carried out to establish the optimal time interval after which peak performance might be expected after return from the altitude training to the low lands

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19

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Medicine and Science in Sport Diving

SUMMARY

Diving with or without self contained underwater breathing apparatus (scuba) has become a popular sport and deserves medical and physiological recognition for this reason as well as for its important military, commercial, and scientific applications

Diving is unique among popular forms of recreation in that it is pursued in an alien environment underwater, where a man must be supplied with something to breathe if he is to remain down more than a few minutes and where the direct and indirect effects of increased pressure can have serious effects These are not sufficient to render diving a prohibitively dangerous activity, but thorough understanding of the possible dangers and adequate

in the means of handling them If they are not thoroughly understood from the standpoints of avoidance, recognition, and handling, the effects of pressure can likewise have disastrous effects

By itself diving is probably not a very effective means of gaining or maintaining a high degree of general physical fitness Individuals who plan to undertake it must not only be in sound condition from the medical standpoint but should have reasonable strength and endurance Emotional stability and a fair degree of "watermanship" are also among the prerequisites

The metabolic and respiratory aspects of diving have received relatively little study Although the most important factors are now reasonably well understood, a number of interesting differences from otherwise similar forms of exertion have been discovered and offer a challenging field for further study

The future of diving should offer considerably greater penetration of the underwater world—both in terms of depth and of time and working ability

underwater—than is possible at the present time Realizing the ultimate potentialities will require a considerable amount of work, not only in the development of better diving apparatus but also in improving our understanding of the needs and limitations of the diver himself Such understanding is indeed necessary before very great advances in equipment and techniques will become possible

INTRODUCTION

One of the most important recent developments in diving is its growing [illegible] of diving to include important new military, scientific, and commercial applications but have also opened it to the average man as a fascinating and practical sport A phenomenal increase in the number of persons involved in diving has resulted

Many of the thousands of people who have taken up spear fishing, underwater photography and like pursuits confine themselves to "skin diving" with simple masks and fins Their time underwater is limited by their breath holding ability, and their activity can be viewed largely as an extension of swimming However, other thousands have equipped themselves with *self contained underwater breathing apparatus* (often abbreviated to *scuba*) and have become divers in the true sense of the word As such, they can expose themselves to a range of depths and times once accessible only to trained navy divers and other professionals The fact that they are free from the lifeline and air hose of the conventional diver has not given them immunity to any of the basic hazards of diving Freedom from surface connections has actually complicated some of the problems Among other things, it makes the "scuba" diver vulnerable to the familiar mishaps of swimming The fact that most of the equipment is simple enough to be put on and used with little or no training has encouraged enthusiasts to believe that there is little or nothing to learn about diving As a result, many have ignored the potential dangers and neglected the simplest requirements of safety

Going underwater confronts man with forces and physiological effects not encountered in his normal environment These impose definite limits and can give rise to serious accidents The diver's safety depends upon his familiarity with these factors and his willingness to respect them

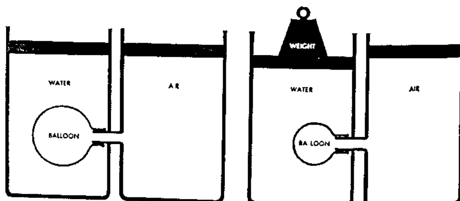
PHYSICAL LAWS INVOLVED IN SKIN DIVING

An understanding of the difficulties encountered by the diver is best gained by reviewing briefly a few basic laws of physics

1 *Air is compressible, water is incompressible*

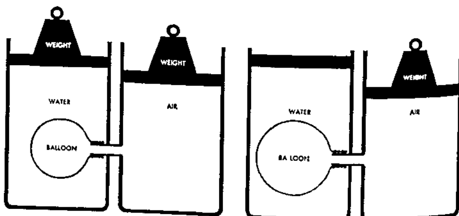
This law can be quickly visualized by referring to the schematic drawings in Fig 19 1 In B, a weight has been added to the cylinder on the left

which contains water This compresses the air in the submerged balloon but not the water, which retains its original volume In C an identical weight has been added to the cylinder containing air This weight adds to the compression of the air However, the balloon returns to its former size because the pressure inside the balloon has been equalized with that of the pressure of the water on the outside



A BALLOON SUBMERGED IN WATER CONNECTED WITH A CYLINDER CONTAINING AIR THE VOLUME OF AIR IN THIS BALLOON WILL VARY INVERSELY WITH THE WATER PRESSURE PLACED UPON IT

B THE ADDITION OF A WEIGHT TO THE CYLINDER CONTAINING WATER COMPRESSES THE AIR WITHIN THE BALLOON THIS HAPPENS IN THE LUNGS DURING DESCENT UNLESS COMPENSATED BY INCREASING PRESSURE OF SUPPLIED AIR



C. AN IDENTICAL WEIGHT ADDED TO THE CYLINDER CONTAINING AIR RE EXPANDS THE BALLOON TO ITS FORMER SIZE BECAUSE PRESSURE INSIDE THE BALLOON HAS BEEN EQUALIZED WITH THE PRESSURE OF WATER ON THE OUTSIDE

D REMOVAL OF THE WEIGHT FROM THE CYLINDER CONTAINING WATER ALLOWS THE AIR INSIDE THE BALLOON TO EXPAND A SIMILAR EXPANSION OF AIR IN THE LUNGS DURING A DIVER'S ASCENT MAY PRODUCE CEREBRAL AIR EMBOLISM

FIG 19 1 *Experiment showing air is compressible, water is incompressible Reprinted from* Clinical Symposia *by permission of Dr Netter and CIBA Pharmaceutical Products Inc*

Adapting this to the human diver, it is apparent that pressure within the air-containing cavities of the body must be raised so as to equal that of the surrounding water If the air pressure within the lungs, the paranasal sinuses, the middle ears, or even the minute air pockets that may be present beneath faulty dental fillings or inlays is not equalized with that of the surrounding water, a relative vacuum will exist Of course the lungs, like the balloon in Fig 19 1, can collapse to a considerable extent without causing difficulty, until the reduced volume of the contained air is under the same pressure as the surrounding water However, the sinuses and middle ears are surrounded by rigid walls If pressure cannot be equalized sufficiently by passage of air through the patent ostia, nature will attempt to distort the surrounding structures or fill the vacuum with transudate or blood, much to the discomfort of the diver

From all this, it can be seen that (1) the greater the depth attained, the greater the pressure of air that must be supplied the diver, and (2) the ostia of the sinuses and eustachian tubes must be patent if difficulty is to be avoided

2 *The volume of a gas varies inversely with the pressure placed upon it* (Boyle's Law)

As we descend into the sea, the pressure increases at the rate of 0.445 pounds per square inch with every foot of descent (assuming a uniform specific gravity of sea water of 1 025) Thus an additional pressure of one pound per square inch is placed upon the diver for about every two feet of descent At 33 feet, he has added one atmosphere, or doubled the pressure exerted upon him at the surface

Going back again to the experiment in Fig 19 1, if the pressure within the balloon (as controlled by the pressure exerted on the air containing cylinder) remains unchanged, the volume of air in the balloon will vary inversely with the pressure of the water surrounding it In D, the removal of pressure upon the water results in an increase in the size of the balloon

Translated to conditions encountered in diving, a lung half inflated at a depth of 33 feet will be fully inflated at the surface A lung fully inflated below the surface may rupture if the diver comes up without exhaling

3 *In a mixture of gases, the partial pressure of each component depends upon the proportionate number of molecules present* (Dalton's Law)

Air is composed of approximately 21 percent oxygen and 79 percent nitrogen Normal atmospheric pressure is considered as being 14 7 pounds per square inch (760 mm Hg) Therefore *at the surface* the partial pressure of nitrogen is 79 percent of 14 7, or 11 6 pounds per square inch The partial pressure of oxygen is 21 percent of 14 7, or 3 1 pounds per square inch

With increasing depth the partial pressure of each of these gases increases proportionately *At 125 feet,* the partial pressure of oxygen is increased from the 3 1 pounds per square inch found at the surface to 14 7 pounds per square inch (21 percent of 125 feet × .445 pounds per square inch increase

per foot of depth plus 14 7 atmospheric pressure) This is approximately the same as the pressure of oxygen a person would receive if breathing pure oxygen at the surface At depths greatly in excess of this (270 feet), the oxygen pressure may be so great as to have a convulsant effect. Partial pressures of atmospheric contaminants, such as carbon dioxide are also increased as depth increases thus augmenting their toxic effects

4 *The components of a mixture of gases in contact with a liquid will dissolve in direct proportion to their partial pressures* (Henry's Law)

As we have mentioned above, the partial pressures of nitrogen at sea level is 79 percent of 14 7 or 11 6 pounds per square inch At 33 feet, with a pressure of two atmospheres, the partial pressure of nitrogen will be doubled, amounting to over 23 pounds per square inch Therefore twice the usual amount of nitrogen will be dissolved in the blood when at that depth Conversely, the blood will hold in solution at the surface only half the volume of nitrogen that will dissolve at 33 feet Thus as one rises to the surface, the excess will tend to come off as bubbles of gaseous nitrogen

The situation is analogous to the carbonation of beverages, where the carbon dioxide that is dissolved under pressure bubbles off as soon as the cap is removed from the bottle Instead of being carbonated, the diver is nitrogenated He is, however, deprived of the benefit of a cap to keep the nitrogen from bubbling off when the pressure is released

HAZARDS OF DIVING

For convenience, the hazards of diving can be divided into those encountered in descent, those that occur while working at the bottom, and those that threaten the diver during ascent

Problems of Increasing Compression During Descent

As will be seen in Fig 19 2, the pressure on the diver is increased by .445 pounds per square inch for every foot of descent At 50 feet the pressure is 36 9 pounds per square inch (absolute) At 100 feet the pressure has increased to 59 2 pounds per square inch, or more than *four times* that to which man is normally accustomed

The most impressive effects of this pressure and of pressure changes are those related to *gas volume* and to the development of *pressure differences* across various structures Both these phenomena can be appreciated by consideration of a few examples Assume that a container that holds 5 liters of air under normal pressure at the surface is sealed and taken to 132 feet, where the absolute pressure is 5 atmospheres If the walls of the container are completely nonrigid, the air inside will be compressed, according to Boyle's law, to a volume of only 1 liter This liter contains five times as many gas molecules and is thus five times as dense as 1 liter of air at surface pressure When the container is brought back to the surface, the air will re-expand to

its original volume The greatest proportional change in volume, in both descent and ascent, occurs close to the surface The volume is halved in the descent from surface to 33 feet but is not halved again until 99 feet is reached, and so on down

If the container in question were rigid and sufficiently strong the descent to 132 feet would cause no change in the volume of the air inside but a difference in pressure would develop between the inside, which remains at 1 atmosphere and the 5 atmosphere pressure reached outside The final difference 4 atmospheres, or nearly 60 pounds per square inch, would amount to a considerable crushing force If the container were rigid but open at the bottom, 4 liters of water would enter as the air became compressed and there would be no difference of pressure in the system

Another method of keeping the inside and outside pressure equalized would be to supply more air, also under pressure, to the container from an external source This process would require 5 liters of air, in terms of volume measured at the surface, for each atmosphere of increase in pressure In this example the mass of air contained at 132 feet would then expand to 25 liters on ascent if it were allowed to do so If it were kept confined, it would remain at a pressure of 5 atmospheres At the surface, this would yield a bursting force of almost 60 pounds per square inch

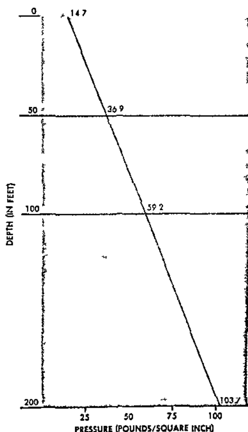


FIG 19 2 *With every foot of descent, pressure increases 445 pounds per square inch At 100 feet the pressure has increased to 59 2 pounds per square inch or more than four times that encountered on the surface*

Calculations as to the 'crushing force' withstood by the diver's body are misleading because the body as a whole, being made up of solids and fluids, is no more likely to be crushed than a bucket of water lowered into the depths Living tissue can be exposed to tremendous pressures without

change attributable to the pressure itself Only when an *unequalized* [illegible] in the same terms as the containers in the *examples cited above* *Pressu* these spaces must be equalized by *admission of additional air on des* or destructive pressure differences will rapidly *develop across* their w Injury due to failure of equalization is often referred to as *barotrauma*

The air containing structures of the body are the middle ear spaces, paranasal sinuses, the lungs and airways, and the gastrointestinal trac person whose eustachian tubes will not transmit air to equalize pressur the middle ear will experience discomfort in the first few feet of desc Further descent will result in increasing pain, with stretching of the eard and with dilation leakage and eventual rupture of blood vessels in both tympanic membrane and the lining of the space Actual rupture of the drum may occur with as little as 10 feet of unequalized descent In th [illegible] duce violent vertigo and nausea The *mechanism of this vestibular reac* is the same as that involved in *caloric tests of equilibrium*

As long as a diver is breathing normally and *has an ample supply of* his lungs and airways will equalize without difficulty If he is holding breath on descent, the air in these spaces will be compressed, and the syst will assume a more "expiratory" position In this case, no difficulty will a until the position of maximal expiration is reached when the volume of equals the residual volume of the lungs plus the volume of the airways *yond this point, further* descent in breath holding will produce pulmon *congestion, edema, and* hemorrhage This accident is generally called *t racic squeeze* Much the *same* situation can be produced by an attempt breathe through an *overlong tube to the* surface (About 18 inches is maximum length for a "snorkel")

The mechanism in "squeeze' *conditions can be considered as* a large cal increase in blood pressure The fluid *portions of the body transmit* external pressure freely, but failure of equalization has left the air space c cerned at lower pressure The resultant differential is manifested as a bu ing force in the blood vessels The area is affected as if a suction cup h *been applied In the* ear, the picture is complicated by the fact that the *ferential also* acts directly across the drum

Air-containing structures attached to the surface of the body are poten sources of local 'squeeze" *When* goggles that have no means of equal tion are worn, excessive descent *may* cause bleeding in the covering me branes of the eyes and lids and even *behind* the eyeballs The usual fa mask which covers the nose as well as the *eyes, is much to be preferred*

cause the diver can keep it equalized simply by letting air out into it through his nose Closed rubber suits of the type often used in sport diving can also produce squeeze unless air is admitted to them by some means during deep descent Here, squeeze is usually noted as a pinching sensation in the area of folds and ridges, and welts and spots of bleeding in the skin may be produced If such a suit is hooded, *external ear squeeze* can also occur

The mechanisms and consequences of external ear squeeze are essentially like those of the more familiar middle-ear situation, and damage to the tympanic membrane may be equally severe, even though the force here is in the opposite direction The lining of the external auditory canal may also give evidence of injury usually in the form of blood blisters close to the eardrum In this accident, bleeding from the external ear does not necessarily indicate eardrum rupture as it does in the middle-ear form of injury Ear plugs are to be avoided in diving not only because they invite external ear squeeze but also because the unequalized pressure may force them deep into the canals

Gas pockets in the gastrointestinal tract do not produce difficulty during descent Since their walls are nonrigid, equalization is accomplished simply by the compression of the gas

The classic form of 'divers' squeeze," sometimes encountered in conventional suit and helmet diving, arises either from loss of the supply of air under pressure to the helmet with venting to lower pressure or from a relative inadequacy of air supply in a fall to greater depth In either case, the helmet itself constitutes a nonequalized space, and the external pressure of the water forces the diver into it

Problems at the Bottom

At any given depth, the *direct* effects of pressure are related to the compression and consequent density of the breathing medium The duration of gas supply in open circuit units is reduced in proportion to the absolute pressure The work of breathing is increased not only in the breathing apparatus but also in the divers' own airways (43,44)

The two most important indirect effects of pressure which are principally encountered at working depth are nitrogen narcosis and oxygen poisoning

Nitrogen Narcosis In diving with air, very great elevations of the partial pressure of nitrogen are encountered Although nitrogen has no evident *physiological effects under normal conditions*, it begins to behave like an anesthetic gas when the partial pressure is sufficiently high When breathing air at 100 feet, most divers show some impairment of thought and judgment and of the ability to perform tasks that require mental or motor skill

At about 250 feet, the average diver has lost most of his usefulness and has become a menace to himself The Navy considers 300 feet an absolute limit for useful air diving Subjectively, *nitrogen narcosis* resembles alcoholic intoxication or the effects of breathing subanesthetic concentrations of

change attributable to the pressure itself Only when an *unequalized difference* of pressure exists can mechanical damage occur The more dramatic view has an element of truth only when the rigid or semirigid air-containing spaces of the body or of those structures attached to the body are considered in the same terms as the containers in the examples cited above Pressure in these spaces must be equalized by admission of additional air on descent, or destructive pressure differences will rapidly develop across their walls Injury due to failure of equalization is often referred to as *barotrauma*

The air-containing structures of the body are the middle ear spaces, the paranasal sinuses the lungs and airways and the gastrointestinal tract A person whose eustachian tubes will not transmit air to equalize pressure in the middle ear will experience discomfort in the first few feet of descent Further descent will result in increasing pain with stretching of the eardrum and with dilation leakage and eventual rupture of blood vessels in both the tympanic membrane and the lining of the space Actual rupture of the ear drum may occur with as little as 10 feet of unequalized descent In the sinuses damage to the lining membrane with leakage of fluid from the blood vessels or actual bleeding can occur as it does in the middle ear If the diver is bare headed in cold water rupture of the tympanic membrane may produce violent vertigo and nausea The mechanism of this vestibular reaction is the same as that involved in caloric tests of equilibrium

As long as a diver is breathing normally and has an ample supply of gas his lungs and airways will equalize without difficulty If he is holding his breath on descent the air in these spaces will be compressed, and the system will assume a more expiratory position In this case, no difficulty will arise until the position of maximal expiration is reached when the volume of air equals the residual volume of the lungs plus the volume of the airways Beyond this point further descent in breath holding will produce pulmonary congestion edema and hemorrhage This accident is generally called *thoracic squeeze* Much the same situation can be produced by an attempt to breathe through an overlong tube to the s rface

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nitrous oxide or other anesthetic gases It is by no means unpleasant and almost by definition prevents a diver from recognizing a hazardous situation and taking effective action The mechanism of the depressant action of nitrogen apparently is closely related to that of gases recognized as anesthetic agents (10,24) For dives to depths greater than can be reached safely by a man breathing air, the Navy employs helium-oxygen mixtures (47,48), but their use in sport diving involves complications that usually outweigh any possible advantage (47)

Oxygen Poisoning It is now well known that increased partial pressures of oxygen can have untoward effects even at the surface. Prolonged therapeutic exposure to exceptionally high concentrations of oxygen (in excess of those achieved by most methods of oxygen therapy) has been recognized for some time as a source of pulmonary irritation and damage (6,11) Also recognized is the ability of oxygen administration to decrease the respiratory drive of certain patients with chronic pulmonary disability and thus to produce loss of consciousness due to retained carbon dioxide (6,11). More recently, the role of oxygen in producing blindness in premature infants has been established (50)

The deleterious effect of exceeding safe limits of exposure to high oxygen pressures in diving appears to be unrelated to the phenomena described above It is also far less widely appreciated, although it has been recognized for many years (4,24) and has been the subject of considerable research (5,24,25,30) The manifestations are those of acute central nervous system stimulation characterized by convulsions The seizures, once under way, are indistinguishable from those of grand mal epilepsy or electroshock therapy The convulsive phenomena are sometimes preceded by symptoms such as localized muscular twitching, nausea, vertigo, anxiety and restlessness, disturbances of vision, and paresthesias When such potential warnings are noted and recognized, the diver can sometimes extricate himself from the situation by ascent before convulsions ensue Not infrequently, however, such warnings are totally lacking or occur so shortly before convulsions that no action can be taken

Although the use of oxygen and "high oxygen mixtures" is not recommended for sportsmen, it has an important place in military diving Table 19 1 presents depth time limits considered reasonably safe for dives with pure oxygen as the breathing medium under the conditions specified Normally, however, a depth of 25 feet is not exceeded during working dives with oxygen The minimum partial pressure of oxygen at which convulsive poisoning can occur has not been established It is apparently less than the 2 atmospheres a partial pressure than can be reached, for example, by breathing of pure oxygen at 33 feet, 50 percent oxygen at 99 feet, or air at about 280 feet

The development of symptoms is preceded by a latent period, which becomes progressively shorter as the partial pressure of oxygen is increased

Both physical exertion and elevated carbon dioxide tensions dramatically shorten the latent period Individual variability in susceptibility to oxygen poisoning is large It has also been noted that intoxication tends to develop more rapidly, at least in some divers, when a given partial pressure of oxygen is encountered in the presence of nitrogen during work at depth This effect is believed to be the result of inadequate pulmonary ventilation, with consequent retention of carbon dioxide by the diver The CO_2 level in the diver s tissues can also be raised if the CO_2 content of the respiratory mixture is

TABLE 19 1 Depth Time Limits* for Dives with Oxygen as the Breathing Medium

Depth (Ft)	Time (Min)
10	240
15	150
20	110
25	75
30	45
35	25
40	10

* Considered safe for dives involving moderate exertion when carbon dioxide content of inspired gas is minimal Accurate measurement of depth is extremely important

elevated This can occur, for example, if the diver is using some type of closed circuit ' apparatus with a faulty CO_2 canister or absorbent

The role of carbon dioxide in oxygen poisoning has been studied intensively by Lambertsen (30) The modus operandi appears to be as follows Under normal conditions, the blood carries oxygen mainly in combination with hemoglobin in the red blood corpuscles Only a small fraction of the total is dissolved in the plasma However, the dissolved fraction increases markedly as the partial pressure of oxygen in the inspired gas is increased As more oxygen is provided in dissolved form, the tissues take less from the hemoglobin As a result there is less reduced hemoglobin available to assist in transporting CO_2 away from the tissues and the tension of CO_2 in the tissues rises

This increase in tissue CO_2 tension is not large But in the brain it is normally sufficient to stimulate the respiratory center and produce an increase in breathing Increased breathing in turn causes a decrease in the alveolar and arterial CO_2 levels The arterioles of the brain are sensitive to arterial CO_2 tension If it is high, they dilate If it is low, they constrict Vasoconstriction, as occurs in this case, causes a reduction in brain blood flow

With decreased blood flow, the brain takes more oxygen out of each drop of blood Although the oxygen tension remains high in blood reaching the

brain, it now drops rapidly as the blood goes through the brain capillaries In effect, this sequence of events greatly reduces the "dose" of oxygen that the brain as a whole receives

What has been related is the usual response, but the protective shutdown

amount of CO_2 in what he is breathing, increased breathing will not lower his alveolar and arterial CO_2 tensions They will, in fact, already be high and will remain so This will also be true if a man's respiratory adjustment to exertion is inadequate, inherently or because of diving conditions or the effects of his respiratory gas mixture It is probable that in both these cases his brain blood flow will also be abnormally high, that his brain will receive an exceptionally high "dose of oxygen throughout the exposure, and that oxygen poisoning will occur with unusual rapidity

If a victim of poisoning is prevented from drowning or injuring himself during convulsions, the likelihood of serious aftereffects is extremely small Convulsions are followed by a period of postconvulsive depression characterized by unconsciousness, restlessness, and irrational behavior, and somnolence, usually in about that order This period may last from as little as fifteen minutes to an hour or so more The patient may then become rational and alert rather suddenly and usually complains of no more than fatigue and headache The convulsions are almost always self limited and followed by a quiescent period of some minutes even if exposure to high oxygen tensions continues The convulsion in progress at the time the oxygen level is lowered is generally the last

adequate to handle the volume of the gas produced by a diver who is working hard In any closed circuit unit, exhaustion or wetting of the absorbent can cause carbon dioxide levels to rise

Normally an excess of carbon dioxide will cause respiratory stimulation to the point of marked discomfort This provides the diver with a clear warning, and he can usually surface before more serious symptoms appear Unfortunately, however, a subnormal respiratory response to carbon dioxide is not uncommon under diving cc
central nervous system depression
ness without any adequate warning
can thus be as insidious a hazard as anoxia

An exceptionally meager response to carbon dioxide, resulting in inadequate pulmonary ventilation and marked retention of carbon dioxide dur

ing a dive, is believed to be responsible for a number of cases of loss of consciousness underwater, even with open circuit equipment Deliberate restraint of breathing to conserve air is practiced by many scuba divers and is considered quite unwise in view of this possibility

A number of deaths in skin diving (without breathing apparatus) have been attributed to overzealous breath holding The use of hyperventilation before the dive to prolong breath holding increases the likelihood that definite anoxia can develop especially when the diver finally starts ascent Breathing oxygen before breath holding produces a spectacular increase in time but allows carbon dioxide tension to approach frankly depressant levels Breath holding in deep skin diving presents several particularly interesting aspects (15,55)

One commonly encountered symptom following exposure to high CO_2 levels is a severe headache This can be expected in 1 out of 5 individuals when the effective percentage of CO_2 (percent CO_2 × pressure in atmospheres) is 5 percent When the effective percentage of CO_2 reaches 8 per cent the headache will invariably occur (23) This headache appears when the diver again commences breathing fresh air The headache is relieved by breathing oxygen

PROBLEMS OF ASCENT OR DECOMPRESSION

During ascent or decompression two major groups of problems exist The first group is caused by the property of a gas to expand as pressure decreases The second is due to the escape of nitrogen from solution in the form of bubbles

Expansion of Air on Decompression With decreasing pressure, any air that has been swallowed will expand and may cause intestinal cramps However, because of the length and distensibility of the intestinal tract, no serious casualties have been encountered from this cause Also, infected sinuses may drain copiously and cause pain during ascent

The most serious results of decompression or pressure reduction occur from the expansion of air in the lungs Air taken into the lung at a depth of 125 feet will increase five times in volume if carried quickly to the surface, where the external pressure is reduced to one fifth Even ascent from lesser depths may cause serious consequences Therefore, the diver must be trained *to ignore his natural impulse to hold his breath under water* and breathe naturally during normal ascent and *exhale continuously during any rapid ascent*

Such training is especially imperative for the scuba diver The diver using self-contained equipment who gets into trouble may have to ditch his gear and *return to the surface as quickly as possible* Under conditions thus conducive to mental panic, an untrained and inexperienced individual is sure to hold his breath to the last possible moment—with dire consequences Even when the diver exhales as he ascends, an occasional individual will suffer

serious lung injury because a local bronchial obstruction (such as a pneumolith) prevents rapid equalization of air pressure in some localized portion of the lung

As the diver ascends, the intrapulmonary pressure progressively distends the alveoli If sufficient air has not been exhaled, some alveoli will rupture

From the point of rupture, the air may dissect along the bronchi and find its way into the mediastinum to create a *mediastinal emphysema* The sign usually encountered in this condition is swelling in the neck and supraclavicular region Crepitus is noted on palpation of these regions The patient may present symptoms such as feeling of fullness in the chest, shortness of breath, dysphagia, and syncope, especially when the neck is flexed The latter is probably due to pressure on the vagus with resulting bradycardia

The X ray will show widening of the mediastinal shadow, with spears of reduced density extending up into the neck These latter shadows represent the passage of air from the mediastinum into the neck along the fascial planes If there is a weakened area on the surface of the lung, such as a bulla or bleb, rupture may take place into the pleural space with the development of spontaneous pneumothorax, with sudden acute dyspnea and pain, which is sometimes so severe as to suggest angina

The most serious consequence of alveolar rupture, or "lung burst" as it is sometimes called, is *air embolism* When air escapes from the lung with sufficient pressure to break into a blood vessel, bubbles of air enter the blood stream The diver is usually in the erect or head up position Air bubbles tend to rise Therefore as the blood carries the bubbles through the arch of the aorta, the bubbles ascend through the carotid arteries and produce *cerebral air embolism*

when rising from even a modest depth

Escape of Dissolved Nitrogen (Decompression Sickness, "The Bends") Since the volume of gas that will be held in solution varies inversely with the pressure, dissolved nitrogen will tend to escape from blood and other tissues as the water pressure decreases during ascent

The appearance of symptoms depends upon (1) the depth and duration of submersion, and (2) the rapidity of ascent

The depth is important because the greater the depth, the greater the partial pressure of nitrogen forcing it into the solution The duration of ex

posure is important because the longer the individual remains under increased pressure, the greater the opportunity for nitrogen to find its way into solution

From Table 19 2 it will be seen that submersion up to 30 feet can be tolerated indefinitely without experiencing decompression sickness However when one exceeds a depth of 60 feet, the length of time necessary to produce 'the bends' decreases sharply One can stay at 100 feet only about 25 minutes without absorbing so much nitrogen that slow decompression is imperative

TABLE 19 2 Depth Time Limits for Air Dives Not Requiring Decompression Stops on Ascent

Depth (Ft)	Time (Min)*
40	120
50	78
60	55
70	43
80	35
90	30
100	25
110	20
120	18
130	15

Navy Standard Decompression Table

The greater the difference between the partial pressure of the gas dissolved

Once bubbles are released the presence and severity of symptoms depend upon where they form or lodge Pain is the presenting symptom and is usually centered around the joints

In order to produce symptoms, a certain amount of tissue deformation must occur Therefore, pain is more likely to be registered in a 'tight" tissue such as a tendon or ligament, than in a 'loose' tissue such as the subcutaneous fat Symptoms will always appear within 24 hours after exposure to pressure

Miscellaneous Accidents and Conditions

Drowning Normally, a well trained sport diver with good equipment is less likely to drown than the average bather at the beach However, the circumstances that he encounters are potentially more hazardous, and even small mishaps can lead to drowning Drowning is almost certainly the lead-

ing cause of death in sport diving However, other diving accidents are often wrongly classified as drowning, and even when drowning is the end result, some other accident is likely to have been the basic cause

Anoxia Anoxia is exceedingly unlikely in the use of open circuit 'scuba

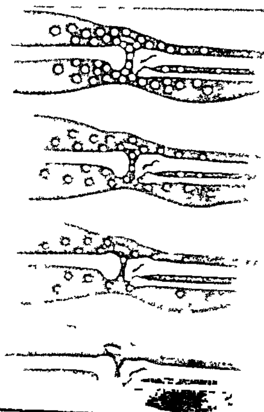


FIG 19 3 *The greater the difference between the partial pressure of the gas dissolved in the tissue and atmospheric pressure, the larger and more numerous are the bubbles and the greater the probability of symptoms Redrawn from* Clinical Symposia *By permission of Dr Netter and CIBA Pharmaceutical Products Inc* © CIBA

ging the cylinders with an

This is not true of closed circuit equipment, even when the cylinder is charged with pure oxygen Here, failure to flush atmospheric nitrogen out of the lungs and breathing bag before the dive introduces the possibility that the gas volume will remain sufficient for comfortable breathing while the oxygen content falls to dangerous levels

The reduction of volume in the system due to metabolic consumption

always occurs without any perceptible increase in breathing or any other adequate warning to the diver Respiratory arrest follows unconsciousness, and cardiac arrest may occur also Very prompt rescue and resuscitation are required to prevent death or permanent brain damage

Carbon Monoxide Poisoning Carbon monoxide poisoning arises oc casionally in the use of open-circuit equipment because of charging cylinders with impure air Whether a given concentration (percentage) of carbon monoxide becomes effectively more toxic with the increase in its partial pressure at depth, as that of carbon dioxide does, has not been established If it does, even carbon monoxide levels that are considered quite innocuous at the surface would be hazardous in diving In any case, the greater partial pressure of oxygen at depth would tend to offset the resulting defect in oxy en transport, and toxicity would become most evident on subsequent as cent Unconsciousness without warning is the most likely result Symptoms such as headache, although frequent in prolonged low level exposures, could not be relied upon to provide any warning

Overexertion Overexertion is one of the more frequent sources of diffi culty in sport diving Hyperpnea and air hunger are familiar and expected limiting factors in strenous exercise even at the surface The limits they im

supply enough air to permit the diver to exert himself vigorously A com mon situation, like that of trying to keep up with a better swimmer, may suddenly bring a scuba diver to the point of desperate air hunger This, in return, may lead to a variety of accidents

Panic Panic can result from very minor mishaps underwater and can turn them into disasters Any loss of presence of mind can be serious as failure to exhale during ascent amply illustrates (air embolism) The diver s temperament is obviously important, but the ability to handle diving emergencies without panic also requires watermanship of a high order and not a little specific training

Cold Cold is a serious problem for divers in many areas Rubber suits of various kinds are available and when properly used provide considerable protection However, sport divers not infrequently find themselves chilled and shivering uncontrollably This in itself does not constitute a diving ac cident, but the attendant loss of tactile sense, dexterity, coordination and ability to hold a mouthpiece, and even of mental competence, can have serious consequences

Injuries from Marine Creatures Injuries due to marine life arise much more frequently from the smaller less awe inspiring forms than from the larger potential menaces Sharks barracuda, manta rays, sea lions, killer whales and the like deserve the diver s respect when encountered By and large, they do not deliberately seek to harm man, and authenticated accounts of attacks on fully submerged divers are rare Injuries from stingrays are common largely because these creatures often lie on the bottom in shallow water and are readily stepped upon The moray eel is frequently vicious when its domain is invaded Painful and sometimes serious injuries involving coral, sea urchins, sea nettles and the Portuguese man of war are by far the most common forms of trauma where these forms of life are found

Underwater vegetable life can be exonerated from harming divers except for the possibility, very real in some areas, of entanglement in such forms as giant kelp

Injuries from Other Underwater Causes Physical injury, entanglement, damage to rubber breathing tubes, and similar mishaps are potential hazards in diving especially around rocks, coral, wrecks, and the like, and particularly so when visibility is poor Improper methods of entering the water with "scuba' and careless ascent in the presence of boats or other overhead obstructions contribute their share of concussions and other injuries

Medical Conditions Common medical conditions that appear to be unusually frequent in sport divers include upper respiratory infections, sinusitis, otitis media and otitis externa, dermatophytoses, and sunburn Fatigue and chilling may contribute to the incidence of respiratory infections and related diseases, and barotrauma is believed to aggravate these conditions Otitis externa probably owes its frequency in part to maceration of the canal lining by frequent and prolonged wetness, and prophylactic measures aimed at drying the canal after diving have met with considerable success The simplest and most likely to be followed is instillation of a few drops of alcohol shortly after the dive

Skeletal Lesions X ray changes in bones of divers have not as yet been observed Two studies of Navy divers have failed to disclose any bone pathology (7,59) In one of these studies (59), some of the divers had experienced symptoms on one or more occasions which could be attributed to a bubble in the medullary cavity For a complete discussion of this problem the reader is referred to Poppel and Robertson (51)

RECOGNITION AND TREATMENT OF DIVING ACCIDENTS

Conditions Requiring Recompression

The most serious mistake possible in dealing with a patient who has been using diving equipment is failure to recognize *air embolism* or *decompres*

sion sickness These may be indistinguishable from each other, but both require recompression if serious and permanent damage or death are to be avoided Often neither diagnosis can positively be made or ruled out These conditions must at least be considered in the diagnosis of almost any abnormal sign or complaint presented by a man who has been underwater *with breathing apparatus* When in doubt, one should recompress Unfortunately, facilities for recompression may not be immediately available This hazard should be taken very carefully into account by all divers and provisions should be made for emergencies

In suit and helment diving, the protection afforded by the rig and the nearly inexhaustible air supply usually available sometimes make recompression in the water a practical substitute for a recompression chamber However, attempting to recompress a man by putting him back in the water with 'scuba" would almost invariably be dangerous and futile Small recompression chambers are recommended for diving organizations

Unconsciousness In a diver unconsciousness presents a particular problem of diagnosis and management, but one practical rule can be given an unconscious diver must be considered a victim of *air embolism* or *decompression sickness* until these conditions can absolutely be ruled out They can readily coexist with seemingly more obvious causes of unconsciousness such as apparent drowning or trauma to the head Not even spontaneous recovery rules them out entirely if any neurological defect remains Unless such measures as artificial respiration are necessary, unconscious persons should be taken immediately to recompression chambers even if considerable distance must be traveled Recompression itself is not known to be harmful in any condition, and almost any other treatment indicated can be applied in a chamber of usual size

Respiratory Arrest When this arises, from any apparent cause, it must be classed with conditions requiring recompression simply because the necessity can rarely if ever be ruled out If air embolism is responsible or coexists, chances of successful resuscitation are negligible without recompression, no matter how prompt and skillful the efforts are Respiration should be administered *while the victim is being transported to a recompression chamber*

The "mouth to mouth" method of artifical respiration appears to be the procedure of choice, not only because it provides good pulmonary ventilation but also because it can be administered in a variety of positions and during transportation It could even be applied with victim and rescuer in the water awaiting pick up A mechanical resuscitator, if it is of good design, is functioning properly, and is correctly used, has definite advantages However, its availability cannot be counted upon in most emergency situations when immediate action is essential

Discomfort in the thoracic or cervical region may indicate the presence of *mediastinal emphysema*, particularly if it is associated with difficulty in

breathing, speech, or swallowing *Subcutaneous emphysema* is sometimes associated with it These conditions, like air embolism (with which they are often associated), can result from exceedingly shallow dives The symptoms may require recompression if severe Recompression temporarily relieves the symptoms of *pneumothorax*, but these are likely to reappear when the patient is returned to normal pressure

Bloody froth coughed up or seen at the nose or mouth, signifies lung injury of some kind Its frequent association with air embolism makes it an exceedingly significant finding in a scuba' diver In breath hold diving or when an excessively long snorkel is used, bloody froth generally indicates *thoracic squeeze* In this situation, conservative therapy and supportive measures are indicated rather than recompression Simple hemoptysis and epistaxis can both arise from barotrauma to the middle ear or sinuses Epistaxis sometimes follows overzealous blowing' in an attempt to equalize pressure on descent

Results of Barotrauma

Inability to equalize pressure during descent can result in considerable damage to the ears and sinuses

In the ear, evidence of failure to equalize may range from little more than hyperemia of the tympanic membrane to gross hemorrhage and rupture There may be a considerable amount of free blood in the middle ear even when hemorrhage in the drum is limited

In most cases, healing is uneventful even after rupture, the less treatment given, the better Most submarine medical officers have concluded that a strict hands off policy yields the fewest complications and most rapid repair The patient is kept out of the water until healing is evident and until he recovers from any condition likely to interfere with equalization of pressure An inhaler or non oily nose drops may be given to relieve congestion and assist drainage of free blood or transudate through the eustachian tube The patient is cautioned against blowing his nose vigorously and should avoid 'ear popping" maneuvers If the tympanic membrane is ruptured, the patient is given strict instructions to keep water and all other objects and materials out of his ear

External ear squeeze," even with rupture, generally requires no treatment except for the patient to stay out of the water and keep water and other materials out of the canal Unless the hemorrhagic blebs are exceptionally large, lancing is not indicated Occasionally, what appears to be a severe otitis externa with purulent exudate may mask an unrecognized rupture of the tympanic membrane with otitis media In such a case, overzealous local treatment with strong agents could be disastrous

Injuries from Marine Life

Some injuries may have constitutional effects because of toxins involved Some forms of coral produce a severe local urticarial response, complicating

the actual injury. The stings of jellyfish, sea nettles, and Portuguese man-of-war, especially the last, can produce intense local pain, pronounced local reaction and occasionally severe systemic reactions resembling anaphylactic shock. Immediate measures should accomplish removal of as much of the offending substance as possible and avoidance of spread to unaffected areas. Tentacles should be removed, a piece of cloth being used to protect the hands. The area is washed with water at once and, as soon as possible, with a basic solution such as dilute ammonia. Local and oral administration of antihistaminics and injection of epinephrine and calcium gluconate have been recommended in the management of the local reaction. However, the experience of Stark (58) indicates that only systemic and topical use of adrenocortical preparations are of real benefit. Systemic reactions demand prompt and vigorous treatment, and cortisone and related agents should be useful here also. Stingray injuries are generally characterized by a sizable and ragged wound, but a toxin is believed primarily responsible for the intense pain that follows and spreads. This toxin is also believed to have systemic effects. Russell (53) recommends the following steps in management of the usual stingray wound confined to an extremity: the victim should immediately wash the wound in sea water after which it should be irrigated, and the epidermal sheath of the stinger removed if this is present; the extremity should be soaked in hot water for thirty to sixty minutes to relieve pain; after debridement and further cleansing, sutures and a sterile dressing are applied. If the wound involves penetration of the thorax or abdomen, the victim is immediately hospitalized for vigorous treatment of secondary shock and other complications.

Further Information Regarding Decompression Sickness

Decompression sickness or the bends most commonly manifests itself by localized pain (Table 19.3). It is usually the only symptom and occurs in 70 percent of cases. The site of the pain is usually in or around the elbow or knee joint. The next two most frequent types of symptoms are those relating to the skin and central nervous system. Skin symptoms are rash and itching. The most common central nervous system symptoms are muscular weakness, vertigo, and aphasia. While rare, a quite serious condition is "chokes," apparently caused by massive bubble formation in the lungs. It is soon fatal if not treated promptly. The onset of symptoms usually occurs within six hours after the dive (Table 19.4). If the first indication of symptoms occurs more than 24 hours after the dive, it is quite unlikely that the condition is due to decompression sickness.

The treatment of decompression sickness is, as stated earlier, recompression. The general principles of the Navy treatment are: (1) limitation of the maximum pressure to 75 pounds and maintenance of this pressure for at least 30 minutes or as long as 2 hours, (2) prolonged recompression for periods of 12–24 hours at pressures of 1 and 2 atmospheres, (3) the inhalation of oxygen at pressure levels equivalent to 2 atmospheres (60 ft.) or less,

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Bloody froth, coughed up or seen at the nose or mouth, signifies lung injury of some kind Its frequent association with air embolism makes it an exceedingly significant finding in a 'scuba" diver In breath hold diving or when an excessively long snorkel is used, bloody froth generally indicates *thoracic squeeze* In this situation, conservative therapy and supportive measures are indicated rather than recompression Simple hemoptysis and epistaxis can both arise from barotrauma to the middle ear or sinuses Epistaxis sometimes follows overzealous 'blowing" in an attempt to equalize pressure on descent

Results of Barotrauma

Inability to equalize pressure during descent can result in considerable damage to the ears and sinuses

In the ear, evidence of failure to equalize may range from little more than hyperemia of the tympanic membrane to gross hemorrhage and rupture There may be a considerable amount of free blood in the middle ear even when hemorrhage in the drum is limited

In most cases, healing is uneventful even after rupture, the less treatment given, the better Most submarine medical officers have concluded that a strict 'hands off' policy yields the fewest complications and most rapid repair The patient is kept out of the water until healing is evident and until he recovers from any condition likely to interfere with equalization of pressure [illegible]

tion and [illegible]

tube The patient is cautioned against blowing his nose vigorously and should avoid "ear popping" maneuvers If the tympanic membrane is ruptured, the patient is given strict instructions to keep water and all other objects and materials out of his ear

'External ear squeeze," even with rupture, generally requires no treatment except for the patient to stay out of the water and keep water and other materials out of the [illegible]

ture of the tympanic membrane with otitis media In such a case, overzealous local treatment with strong agents could be disastrous

Injuries from Marine Life

Some injuries may have constitutional effects because of toxins involved Some forms of coral produce a severe local urticarial response, complicating

the actual injury The stings of jellyfish, sea nettles, and Portuguese man-of war, especially the last, can produce intense local pain, pronounced local re action and occasionally severe systemic reactions resembling anaphylactic shock Immediate measures should accomplish removal of as much of the offending substance as possible and avoidance of spread to unaffected areas Tentacles should be removed, a piece of cloth being used to protect the hands The area is washed with water at once and, as soon as possible, with a basic solution such as dilute ammonia Local and oral administration of antihistaminics and injection of epinephrine and calcium gluconate have been recommended in the management of the local reaction However, the experience of Stark (58) indicates that only systemic and topical use of adrenocortical preparations are of real benefit Systemic reactions demand prompt and vigorous treatment, and cortisone and related agents should be useful here also Stingray injuries are generally characterized by a sizable and ragged wound, but a toxin is believed primarily responsible for the in tense pain that follows and spreads This toxin is also believed to have systemic effects Russell (53) recommends the following steps in manage ment of the usual stingray wound confined to an extremity the victim should immediately wash the wound in sea water after which it should be irrigated, and the epidermal sheath of the stinger removed if this is present, the extremity should be soaked in hot water for thirty to sixty minutes to relieve pain, after debridement and further cleansing, sutures and a sterile dressing are applied If the wound involves penetration of the thorax or abdomen, the victim is immediately hospitalized for vigorous treatment of secondary shock and other complications

Further Information Regarding Decompression Sickness

Decompression sickness or the bends most commonly manifests itself by localized pain (Table 19 3) It is usually the only symptom and occurs in 70 percent of cases The site of the pain is usually in or around the elbow or knee joint The next two most frequent types of symptoms are those relating to the skin and central nervous system Skin symptoms are rash and itching The most common central nervous system symptoms are muscular weakness, vertigo, and aphasia While rare, a quite serious condition is "chokes," apparently caused by massive bubble formation in the lungs It is soon fatal if not treated promptly The onset of symptoms usually occurs within six hours after the dive (Table 19 4) If the first indication of symptoms occurs more than 24 hours after the dive, it is quite unlikely that the condition is due to decompression sickness

The treatment of decompression sickness is, as stated earlier, recompres sion The general principles of the Navy treatment are (1) limitation of the maximum pressure to 75 pounds and maintenance of this pressure for at least 30 minutes or as long as 2 hours, (2) prolonged recompression for periods of 12–24 hours at pressures of 1 and 2 atmospheres, (3) the inhala tion of oxygen at pressure levels equivalent to 2 atmospheres (60 ft) or less

to promote the rapid elimination of nitrogen The treatment can be as short as 2½ hours or as long as 38½ hours (Table 19 5)

Indications are that there is no relation between the depth of dive and the depth at which symptoms are relieved A diver may incur decompression

TABLE 19 3 Symptoms of Decompression Sickness in 113 Dives

Symptoms	No of Patients with Each Symptom
Localized pain	107
Numbness	10
Muscular weakness	10
Rash	9
Visual disturbances	8
Vertigo	4
Aphasia	2
Headache	2
Unconsciousness	2
Nausea	1
Chokes	1

Number of patients with one symptom 79
Number of patients with two symptoms 29
Number of patients with more than two symptoms 5
Number of patients in which pain was the only symptom 77

TABLE 19 4 Time of Onset of Symptoms After Exposure to Pressure

Time of Onset	Number of Cases
During or immediately after decompression	14
Within ½ hour	15
½ to 1 hours	12
1 to 2 hours	16
2 to 4 hours	20
4 to 6 hours	18
6 to 8 hours	4
8 to 10 hours	4
10 to 12 hours	4
12 to 14 hours	1
14 to 16 hours	0
16 to 18 hours	2
18 to 24 hours	2

TABLE 19 5 Treatment of Decompression Sickness and Air Embolism

Stops	Bends—Pain Only		Serious Symptoms	
Rate of descent—25 ft per min Rate of ascent—1 minute between stops	Pain relieved at depths less than 66 ft Use table 1 A if O_2 is not available	Pain relieved at depths greater than 66 ft Use table 2 A if O_2 is not available If pain does not improve within 30 min at 165 ft the case is probably not bends Decom press on table 2 or 2 A	Serious symptoms include any one of the following 1 Unconsciousness 2 Convulsions 3 Weakness or inability to use arms or legs 4 Air embolism 5 Any visual disturbances 6 Dizziness 7 Loss of speech or hearing 8 Severe shortness of breath or chokes 9 Bends occurring while still under pressure Symptoms relieved within 30 minutes at 165 ft Use table 3	Symptoms not relieved within 30 minutes at 165 ft Use table 4

Pounds	Feet	Table 1	Table 1 A	Table 2	Table 2 A	Table 3	
73 4	165	—	—	30 (air)	30 (air)	30 (air)	30
62 3	140	—	—	12 (air)	12 (air)	12 (air)	
53 4	120	—	—	12 (air)	12 (air)	12 (air)	
44 5	100	30 (air)	30 (air)	12 (air)	12 (air)	12 (air)	
35 6	80	12 (air)	12 (air)	12 (air)	12 (air)	12 (air)	
26 7	60	30 (O_2)	30 (air)	30 (O_2)	30 (air)	30 (O_2) or (air)	6
22 3	50	30 (O_2)	30 (air)	30 (O_2)	30 (air)	30 (O_2) or (air)	6
17 8	40	30 (O_2)	30 (air)	30 (O_2)	30 (air)	30 (O_2) or (air)	6
13 4	30	↓	60 (air)	60 (O_2)	2 hrs (air)	12 hrs (air)	First The
8 9	20	↓	60 (air)	↓	2 hrs (air)	2 hrs (air)	First Ther
		5 (O_2)		5 (O_2)			
4 5	10	↓	2 hrs (air)	↓	4 hrs (air)	2 hrs (air)	First Ther
Surface		↓	1 min (air)	↓	1 min (air)	1 min (air)	1

sickness as the result of a dive to 100 feet and need to be recompressed to 165 feet to obtain relief of his symptoms On the other hand the longer recompression is delayed the greater the pressure required to obtain relief of the symptoms

Complications such as shock, convulsions, and dehydration may accompany decompression sickness and of course these require medical attention The most common complication is that of excessive loss of water and electrolytes It is usually hot in recompression chambers, and the air is almost completely saturated with water vapor Fluids and electrolytes should be administered, especially in cases where the treatment may be prolonged The physician's own acuity and judgment will be markedly impaired by nitrogen narcosis at the higher pressures involved in recompression If possible he should remain outside the chamber and direct the activities of a trained person on the inside with the patient

To be useful chambers must be able to withstand 50 psi If possible, the patient should be recompressed to at least one atmosphere (15 lbs) beyond the depth of relief, and he should then be brought up in accordance with Table 19 5 columns 2A or 3, depending on circumstances In the absence of a chamber, oxygen inhalation is recommended but is likely to be of little value (See 60 for further details)

PREVENTIVE MEASURES

Sport diving need not be unduly hazardous Many of the accidents discussed are readily preventable if reasonable precautions are taken Danger seems to be one of the attractions of scuba diving, and its complete elimination is not possible However, through knowledge and skill it is possible to live dangerously without killing yourself '

'Scuba" diving should never be done alone, and indeed the 'buddy system" in which each partner is responsible for the other should always be used There are few underwater emergencies that cannot be handled by partners who have experienced expert instruction and supervised drill

A diver cannot be safer than in the midst of a group that pays ample attention to the essentials of safety" adequate background knowledge competence in general and specific skills, good equipment, sound diving practices, and readiness for handling emergencies

Physical Requirements

Apparatus—Breathing Mediums It has been pointed out that the mixture the diver breathes underwater is considerably more dense than ordinary air The components of this mixture also exert a greater than usual partial pressure It is therefore a matter of considerable importance that the apparatus have an acceptable respiratory resistance This should not be greater than 5 cm H_2O/l /sec at atmospheric pressure, during both inspiration and ex

piration Preferably, the resistance should be somewhat less, about 3 5 cm H_2O/l /sec during expiration For this reason, respiratory equipment developed for use at atmospheric pressure is hazardous when underwater Using aviation respiratory equipment underwater is equivalent to inviting suicide Most sport divers employ open circuit demand type units, an example of which is the "Aqua Lung" The heart of such a unit is the demand regulator, which opens to supply the gas required by each breath Exhaled gas is discharged into the water, and there is no rebreathing Pure compressed air is the gas of choice for charging open-circuit equipment, and the average sport diver derives only added limitations and hazards from using anything else A few types of *closed-circuit* rebreathing units are available and in use These consist of a breathing bag, carbon dioxide absorption canister, various valves and tubes, a mask or mouthpiece, and a gas supply cylinder The principle of operation is the same as that of many types of basal metabolism and anesthesia equipment Pure oxygen must be used in such a 'scuba" Although closed circuit units have certain advantages and must be used in military diving situations, they are generally considered unsuitable for sport diving Specialized types of equipment that involve partial rebreathing to conserve gas and permit utilization of various gas mixtures have been developed (49) Their use is confined almost entirely to special military purposes, and they have no place in sport diving unless further development reduces the difficulty and risk involved

RESPIRATORY DATA IN UNDERWATER ACTIVITIES

Introduction

[illegible]

been few in number and contributed by a small number of interested groups Although by far the widest application of diving is now in the realm of pure sport, little general scientific interest has as yet come into play Some work has been of limited value because of limited objectives, as in evaluations of breathing apparatus that might have yielded more useful physiological data Some has had its value obscured by security classification or interment in government reports of limited availability In part, the difficulty of obtaining satisfactory measurements accounts for the scarcity of data concerning certain variables

Despite these shortcomings, enough information has been accumulated to delineate several phases of the subject quite accurately and to demonstrate the existence of unexpected phenomena and the need for further study in other aspects of the field

This discussion will be confined mainly to the gross metabolic and re-

spiratory aspects of underwater physiology" Most of the detailed work devoted to oxygen poisoning, decompression, inert gas narcosis, carbon dioxide phenomena, and other problems described in the earlier portions of this chapter must be considered beyond its scope

The history of metabolic and respiratory studies in diving is brief This is largely accounted for by the fact that these matters were of relatively little concern when almost all diving was done with surface supplied equipment with a more or less unlimited supply of breathing medium available from banks or compressors The development of self contained equipment, in which the supply of gas and the ability to absorb carbon dioxide is necessarily limited, gave the diver s requirements new importance

METHODS OF STUDY

The procedures for respiratory and metabolic studies in underwater work are basically the same as those applied to similar problems on dry land but the problems of submergence and hydrostatic pressure may require modifications that obscure the resemblance Obtaining measurements from an underwater swimmer who is loose in his native habitat presents particular problems Only a few types of observation have proved possible without restriction of the subject s freedom or unjustifiably impressive instrumentation Oxygen consumption can be measured with reasonable accuracy by

The physiologist s problems are somewhat simplified in dealing with forms of underwater work where the diver stays in one spot and can be connected to sampling tubes recording cables and the like, and where expired gas can be collected and measured

The elusive swimmer himself can be pinned down while still swimming—by means of a variety of devices Such devices can be valuable and are quite essential when connections to the subject are required or when swimming must be done in a pressure tank or similarly limited space But in even the best of such forms of captivity, the swimmer has ceased to be his normal free finned self, and the unhesitating transfer of data to the untethered state can lead to errors

Caution in the transfer of data must be carried several steps further when the circumstances of study require the swimmer' to be dry as well as stationary The energy cost of treading a mill may be made equal to that of

to be conducted submerged—even at great cost in ingenuity and in convenience

OXYGEN CONSUMPTION

The pioneering studies of Donald and Davidson (14) were conducted by the pressure-drop method mentioned above. They included measurements in conventional forms of diving as well as in underwater swimming. The average values they reported in the former ranged from 0.6 liters per minute (l.p.m.) for walking slowly in a tank to 1.77 l.p.m. for walking at a maximal rate on a muddy bottom. Their studies of swimming were limited, but they reported an average of 2.17 l.p.m. at speeds from 0.8 to 1.0 knots (k.)[1] and 3.35 l.p.m. at 1.0 to 1.4 k. The higher speeds were maintained only briefly.

From the standpoint of designing self-contained diving equipment, swimming is by far the most important form of underwater work. Almost all of the more recent investigations have concentrated upon it although more information about other activities—including walking, pulling along a line, operating propulsive devices, and the like—would be of value for its own sake and for comparative purposes.

Oxygen consumption studies in swimming conducted during CUSP (52) were not very extensive, and although they indicated the right order of magnitude, the average 'normal speeds' determined were lower and the mean

a scales within his view. The results indicate that the selected force was either too low or too ill maintained by the subjects, to be representative of free swimming at normally selected speeds.

Questionable values obtained during CUSP, and many questions that remained unanswered, led The Experimental Diving Unit in England to undertake a larger scale study of oxygen consumption in underwater swimming in the fall of 1952 (40). The pressure-drop method was used with a small calibrated cylinder attached to each breathing apparatus and a calibrated gage attached to each cylinder. Swims were conducted in a large indoor pool with a 200-foot course (a rounded rectangle) marked on the bottom. Controlled swimming speeds were obtained by a system of underwater markers and time signals. Each time a swimmer passed a specified point, his gage was read. The subjects used fins of the type almost universally employed at that time (Voit Churchill).

The data obtained are presented graphically in Fig. 19.4. Although the mean values form a relatively smooth curve, the ranges indicate that individual variations were very large. While the same individuals tended consist

[1] A knot is defined as a speed of one nautical mile per hour. A nautical mile is equal to 6080 feet (1.15 land miles). With little error (about 1.3 percent), 6080 can be rounded to 6000 feet or 2000 yards. The knot is thus a very convenient unit of speed measurement as well as one consistent with naval usage. Where speeds were originally reported in other units they have been converted to rounded knots (6000 ft. per hr.) for ease of comparison in this discussion.

ently to be "high" or "low," repeated runs at the same speeds and comparison of values from adjacent speeds indicated that a given subject's performance could vary considerably from day to day

Valuable information concerning practical swimming speeds was also obtained The subjects found speeds below 0 7 kilometer uncomfortably

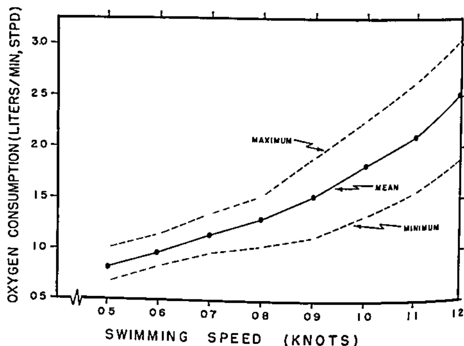


FIG 19 4 *Oxygen consumption in underwater swimming at various speeds Subjects UDT swimmers Experimental Diving Unit, 1952* (40)

slow and insufficient to provide ability to "plane" themselves up or down for depth control At these speeds, errors in buoyancy compensation could require more effort to be exerted in achieving the desired depth than for forward movement There was general agreement among the subjects that speeds between 0 8 and 0 9 knot would be chosen for normal operational swimming Speeds above 1 0 knot were uncomfortably fatiguing and could not be maintained at all by some subjects with the older breathing units until carbon dioxide absorption capacity was increased The top speed studied (1 2 knot) was found to be exhausting and could be maintained by most subjects barely long enough for accurate measurements to be obtained (about 15 minutes) In some cases, it was doubtful that a steady state was achieved in this period

inc ,

"efficiency was roughly constant up to 0 8 knot and dropped sharply

above that speed Calculations indicated that, at best, an underwater swimmer could cover only one fifth or one sixth as much distance per liter of oxygen consumed as a man walking or running on dry land

Many further studies proposed at EDU involved swimming in the confines of a pressure tank about 10 feet in diameter and obtaining measurements that required direct connections to the swimmer For this reason, development and 'calibration" of a reliable 'stationary swimming' device was undertaken in conjunction with the cited study and employing the same subjects (41) (The device is also pictured and described in reference 47) Weights were employed to maintain a constant opposing force

The calibration process involved determining on the basis of oxygen consumption what opposing force was required to simulate a given speed of free swimming

The 'underwater trapeze,' as it came to be called proved to be an indispensable aid in EDU s subsequent underwater studies Despite certain limitations, it permitted the physiological responses of large numbers of subjects and the performance of a great variety of breathing devices to be studied under a wide variety of conditions with reasonable simulation of operational activity

Carbon Dioxide Production

Measurement of carbon dioxide production has not been accomplished during unrestricted swimming and would be very difficult It is not entirely simple even with the instrumentation that can be applied to a tethered swimmer The apparatus described by Goff and Specht s group (18) could be modified to permit this measurement, and it has been accomplished by an open circuit method at EDU as a means of validating other measurements but without attempts to relate it directly to specific swimming speeds Simultaneous measurements of carbon dioxide output and oxygen consumption have not been made

The almost complete lack of information concerning carbon dioxide production in underwater work is probably not serious It has been assumed that the usual relationships with oxygen consumption, expressed in respiratory quotients would apply as in all forms of exertion For such purposes as designating carbon dioxide absorption systems, it is generally assumed that the R Q will approach unity during fairly heavy work, so the values obtained for oxygen consumption are applied It is known, however, that the moment to moment output of carbon dioxide can be greater than the oxygen consumption at least for short periods, and information concerning the extent to which this occurs in diving would be desirable

Pulmonary Ventilation

The volume of gas moved in and out of the lungs (often expressed as respiratory minute volume—RMV) is of interest in underwater work for

several reasons In itself, it is not of much concern except in the use of open circuit demand 'scuba," of which the 'Aqua Lung" is the most familiar example Here, together with the diver s depth, it directly determines the quantity of compressed air he must carry for a given job, or conversely, whether the supply he can carry will be adequate

Respiratory Rate and Tidal Volume

The frequency of respiration and the volume of individual breaths are of secondary importance to other measures but cannot be neglected They affect certain aspects of scuba design and appear to have important bearing on CO_2 retention problems to be discussed

The EDU oxygen consumption study (40) included counting of respiratory rates These were found to be quite variable and inconsistent in their trends While a subject would maintain about the same rate throughout a given swim, he might vary it considerably in another swim at the same or similar speed Differences between subjects were pronounced Although rates tended to increase with increasing speeds, some subjects did not show this trend Among all subjects and all runs, the respiratory rates were between 9 and 39 breaths per minute (b p m) At speeds from 0 7 to 1.0 kilometer, the majority of rates were between 10 and 25 b p m , and only 3 subjects had rates about 25

Many trained swimmers have been taught to attempt conservation of air by slow, deep breathing Many have a habitual postinspiratory pause Specht, *et al* (57), studied such men during tethered swimming in moving water The respiratory rates increased little until speeds of 1 0 kilometer and above were reached At the lower speeds, the mean rate was about 10 b p m with a range from about 6 to 17 Even at the higher swimming speeds, no rates over 28 b p m were reported Throughout the speed range, the mean tidal volume was in the order of 2 5 to 3 liters

Control of Respiration

Knowledge of the mechanisms that regulate breathing, especially during exercise, has developed slowly and still contains important gaps This lack of knowledge, and a too ready acceptance of conclusions reached on dry land, has led to some interesting surprises for the investigators of respiration in diving The full story of these discoveries and problems cannot be given here, but an account of some of the salient points should be of interest

One of the earliest preconceptions to be upset was that a man exposed to a rising level of carbon dioxide in his inspired gas would necessarily experience obvious hyperpnea and "air hunger" This, it was assumed, would give him ample warning that something was wrong with his breathing apparatus and permit him to terminate the dive before serious difficulty developed

During World War II, Barlow and MacIntosh (2) investigated the diving

accident known as "shallow water blackout." They discovered that when breathing oxygen during exercise, some subjects had little respiratory response to carbon dioxide in their inspired gas. Unaware of any abnormality they would continue working until the CO_2 level reached the point of causing unconsciousness. More recently, Miles (45) has indicated that there may be other causes for the accident in question, but this relative absence of respiratory stimulation by carbon dioxide must often be involved and represents a valuable discovery in itself.

Later Schaefer found that a subnormal respiratory response to carbon dioxide was virtually characteristic of submarine escape training instructors, men who make prolonged and frequent deep "breath-hold dives" in the course of their work. This low re-activity was demonstrable even during rest under normal conditions and was associated with unusually high normal resting alveolar CO_2 tensions in the men concerned. Schaefer has recapitulated these observations in a recent paper (56) and relates them to a habitual pattern of slow, deep breathing. Miles (46) has also reported similar findings in Royal Navy diving personnel, and Lanphier has reported markedly subnormal CO_2 responses in EDU subjects (37,38).

Individuals with subnormal respiratory sensitivity to CO_2 and unusual respiratory adjustments to exercise appear to be far more common in diving than in the general population or among otherwise comparable athletes. Such characteristics are evidently not unheard-of outside of diving, but it does not seem likely that an unconscious self-selection process could account for the predominance of such individuals in underwater work or the extent of their deviations from the respiratory norm. The existence of an adaptive process of some kind is probable. More extensive longitudinal studies of divers are desirable to establish this. Its details deserve investigation not only for their own sake but for the light they may shed on normal mechanisms and on similar alterations that can, for example, accompany pulmonary disease. In like manner, it seems probable that better understanding of the effects of depth and breathing media on respiration would also provide information of value well beyond the immediate concerns of diving.

SUMMARY AND CONCLUSIONS

Metabolic cost and other respiratory variables in underwater activity have been the subject of a relatively small number of studies by a few groups of investigators, but not much understanding has been gained and numerous problems needing continued investigation have been defined.

Oxygen consumption in underwater swimming has been investigated relatively well, but numerous questions still deserve answers even in this area. At practical swimming speeds, in the neighborhood of 1.0 kilometer, swimming consumes oxygen at average rates around 1.5 l.p.m. Individual variations are large. Higher speeds can be maintained only for brief periods,

and although these are associated with large increases in oxygen consumption, the limiting values still remain well below those for most forms of dry land exercise This fact has not been explained Not only is underwater swimming a slow mode of propulsion but its efficiency is exceedingly low While its efficiency can be improved by perfecting swimming techniques and better fins, it remains far below that of common forms of work While propulsive devices will largely replace swimming as a means of covering distance underwater, it will remain important for work of limited range and in the field of sport

Carbon dioxide production in underwater work remains almost completely uninvestigated

Measurements of pulmonary ventilation in trained underwater swimmers yield values below those anticipated for the associated rates of work, and elevated carbon dioxide levels appear to be a direct consequence of this discrepancy Neither these observations nor the apparent further depression of ventilation during work at depth and with certain breathing media have been explained adequately Low respiratory rates and large tidal volumes are characteristic of trained underwater swimmers, but their significance in terms of the efficiency of respiration has not been established

Study of the physiology of underwater exercise can involve unusual problems of equipment and instrumentation, but many important questions are well within the capabilities of many
vast increase in underwater activity, notab
add considerable impetus to investigation
field The answers, when found, should not only assist man's penetration of the underwater world but should also prove of value on the playing fields, in the hospitals, and as an addition to physiological understanding as a whole

DIVING AND FITNESS[2]

If the term *fitness* is used in a broad sense, it has two principal aspects in connection with diving an individual s ability to engage in diving in the first place, and the effect of diving on his physical status Both of these, in turn have numerous ramifications

Fitness for Diving

In deciding whether a person is 'qualified' to take up diving or not, four main points deserve consideration his basic physical condition, his actual strength and endurance, his motivation and other psychological factors, and his ability to handle himself in the water

[2] The opinions or assertions contained herein are those of the authors and are not to be construed as official or reflecting the views of the Navy Department or of the Naval Service at large

From the rather strictly medical standpoint, the main physical requirements of diving are (1) ability to equalize pressure in the body's air spaces, and (2) basic capability for doing hard work. The former involves freedom from ear or upper respiratory conditions that could interfere with equalization of the middle ears and sinuses or that might be aggravated by the pressure changes associated with diving. The lungs should be free of evidence of any disease that might conceivably lead to trapping of air during ascent. Capability for doing hard work requires not only freedom from diseases of the lungs, heart, and blood vessels but also a normal musculoskeletal system and absence of any condition adversely affected by exercise. Less often an issue but no less important is freedom from any condition that might cause unconsciousness or complicate accidents like oxygen poisoning or decompression sickness.

The Navy has rather strict physical standards for the selection of divers (47). In addition to specifying disqualifying defects of medical history and examination, these impose an age limit of 30 for initial assignment to diving training and of 40 as the normal limit for continuation of diving duty. Candidates are also required to demonstrate their ability to equalize pressure (to 50 pounds per square inch) and to breathe oxygen (at rest for 30 minutes at pressure equivalent to a depth of 60 feet) in a recompression chamber. Although it is rather uncommon for individuals already on active duty and volunteering for diving training to be found wanting, some of the Navy standards may be too stringent for practical application to civilian sport divers. An approach that is perhaps more practical for civilian purposes is presented in *The Science of Skin and SCUBA Diving* (12). This presen [illegible] medical history form for the [illegible] findings and impression s on

The psychological aspects of fitness are perhaps the most difficult to assess and to do anything about. Some of the personality types attracted by diving, especially as a sport, seem the least likely to be safe divers or reliable diving partners. Unfortunately, these are also the least likely to be dissuaded by a physician or physical director who senses their recklessness or emotional instability.

Effects of Diving on Fitness

The effects of diving on fitness can be summarized very briefly. Although under certain conditions diving can be very strenuous, it alone is unlikely to bring about a high degree of fitness. A limited number of muscles are used in diving—for example, the arms may be scarcely used at all. Moreover, few people engage in diving often enough or vigorously enough to elevate fitness markedly. Consequently, as an important safety measure, it is recommended that individuals interested in diving maintain a reasonable level of

fitness by means of regular programs of exercise, including such activities as weight lifting and other strength activities and running games, handball, squash and other "wind" activities

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Fatigue and Physical Fitn

SUMMARY

No attempt is made in this chapter to define fatigue, but some of its ma festations will be described There is at least one common feature amo these manifestations whatever the type of fatigue—a disturbed balance b tween wear and repair Attention will be directed to the factors which affe the capacity of man and dog for work and the fatigue associated with e hausting work of short or long duration In races of short duration, pe speeds are reached at about 100 meters but fatigue associated with hi lactic acid concentration in the blood prevents this rate from being mai tained for more than a few seconds In this sort of activity, energy reser are used that do not require oxygen An oxygen debt is contracted whi is paid off by oxidative reactions in recovery

As the duration of work increases, the rate falls off and a larger and larg portion of the energy is supplied directly by oxidative reactions Fatigue i volves depletion of the most efficient fuel, carbohydrate, and may also i volve breakdown because of high body temperature Fitness depends o efficiency, i e , a minimum of wasted effort, and also on a high capacity of th respiratory-circulatory systems for supplying oxygen to tissues

It is significant that the President's Council on Youth Fitness recommen more research designed to assess the need for youth fitness and to provide yardstick for fitness progress

INTRODUCTION

Fatigue is a common effect of exercise It is always experienced after e hausting exercise Yet, we all know that the fatigue caused by a 60-mete dash differs greatly from that caused by a 10-mile walk Hence, instead o trying to describe in general terms the nature of fatigue, it is much simple to describe the specific manifestations of fatigue in exercise of short an

long duration and of high, medium, and low intensity. We shall see at least one characteristic in common a disturbance in balance between wear and repair

It may help to understand the varying nature of fatigue by referring to a concept used in toxicology, that of *Ct* In this expression, *C* is the concentration of the toxic vapor and *t* is the duration of exposure The product *Ct* is constant or nearly so for a wide range of concentration and of duration of exposure For example, if we double the concentration and halve the duration of exposure, the toxic effect will be the same The same concept can be applied, in a rough nonquantitative sense, to muscular work the capacity for work and the fatigue induced by it are related to its intensity and duration At one extreme is the 60 meter dash lasting about five seconds and at the other, a day's labor in heavy industry which, with overtime, may *last for twelve hours In the first example, the work is accomplished with the* reserves of oxygen in the blood and lungs plus the body's resources of anaerobic energy In the second, the work must be entirely aerobic Between these two extremes are found activities in which the energy is supplied partly by aerobic, partly by anaerobic reaction In simpler terms work of long duration depends on the oxidation of carbohydrate or fat while intense work of short duration can be accomplished without oxidative reactions, these take place during recovery

FATIGUE IN EXHAUSTING EXERCISE OF SHORT DURATION

Maximal Rate of Energy Output

In bursts of all out exercise, man reaches his maximal rate of energy output within a few seconds and can maintain this rate for twenty or thirty seconds Thereafter, the rate falls off As will be seen in Table 20 1, based on records published in the *World Almanac* (29) the rate in the fastest 200-meter run is 9 90 meters per second and in the 400-meter run, 8 73 meters per second

Why is it impossible even for a champion to run further than 200 or 300 meters at 9 90 meters per second? There is no simple, complete explanation, but this much is well known when the store of chemical energy that can *be transformed without oxygen is exhausted, muscles come to a standstill* But there is more to the explanation than this a large number of facts must be taken into account The phenomenon of tetanic contraction seen in isolated nerve muscle preparations is characterized by a period of sustained performance that may last for minutes or even hours depending on the frequency of stimulation Eventually, performance begins to decline but does not fall to zero for some time Carrying over these observations to the case of the champion sprinter, we can assume that he reaches the point of

TABLE 20 1 Running Records for Man

Distance meters	Record min	sec	Rate m /sec
60		6 6	9 09
100		10 2	9 80
200		20 2	9 90
400		45 8	8 73
800	1	46 6	7 52
1,500	3	41 8	6 76
2,000	5	7 0	6 51
5 000	13	51 2	6 02
10,000	28	54 2	5 77
15 000	44	54 6	5 57
20,000	59	51 7	5 57
25 000	79	11 8	5 26
30 000	95	23 8	5 24

SOURCE *World Almanac* 1956 (29) The 60 meter record was established indoors all others are outdoor runs

decreasing performance in about 20 to 30 seconds He has not exhausted his reserves of anerobic energy, but he has reached the limit beyond which these reserves cannot be transformed into mechanical energy at the peak rate

LESSONS FROM COMPARATIVE PHYSIOLOGY

Physiologists have learned much about exercise in man by comparisons of the capabilities and performances of other species Man is slow as compared with some of his four legged friends—notably the dog and the horse These four legged runners can run much faster than man The greyhound, for example, can run for 400 meters at *16 6 meters per second*—two thirds faster than man's top speed in the 200-meter race While a full explanation cannot be given, the greyhound has the following advantages

The effort is divided between four legs a larger fraction of the body is engaged in useful work than in man

The greyhound s body is parallel to the ground and hence the resistance offered by air is less per unit of body weight than in man

The greyhound, per unit of body weight, has a larger heart and larger blood volume than man On this account, his capacity for transporting oxygen is greater than man s

The heart rate of the greyhound can increase from 60 to 300, a factor of 5 Man can increase his from 60 to 180, a factor of 3 The relative abilities to increase cardiac output probably are in the same proportion

Fundamentally, the chemical reactions involved in muscular exercise are much the same in dogs as in man the differences are anatomical and func-

tional, not biochemical For example, in both dog and man lactic acid reaches high levels in intense exercise of short duration

Lactic Acid

What is the significance of the accumulation of lactic acid in bursts of all out exercise? Years ago, lactic acid accumulation was thought to be an index to fatigue with recovery going hand in hand with removal of lactic acid We now realize that recovery is more complicated than this For one thing, it appears that the oxygen debt contracted during anaerobic work is re paid by two processes One of these is rapid and does not involve the re moval of lactic acid The other, involving removal of lactic acid is much slower Margaria and associates (19) have called these components the alactacid and the lactacid debts, respectively It was concluded from their work that the alactacid debt is incurred in all forms of exercise and that in a man of ordinary size it can reach a level equivalent to 2 5 liters of oxygen No lactacid debt is incurred in light or even moderate exercise In walking or running for example, the metabolic rate may be increased four or five times before any lactacid debt is incurred These conclusions are summa rized in Fig 20 1, based on a large series of observations on a distance runner weighing about 65 kg He ran for from seven to ten minutes at various rates and grades

debt was directly proportional to
ıctacid debt was contracted after
- 5 liters per minute, or two thirds
ctacid debt increased
his maximum attain

Studies of the rate of movement of lactic acid in and out of red cells have thrown new light on the process of contracting and paying the oxygen debt In the first approach made to this problem by Dill and associates (10) a man ran to exhaustion in 40 seconds on the treadmill and then jumped onto a cot As quickly as possible, usually within 10–15 seconds of the end of work, the first of a series of samples of blood was drawn from his femoral vein By leaving the needle in the vein and changing syringes, additional samples were taken every 15 seconds during the first two minutes and less often during the next ten minutes Each sample was cooled in ice within 20 seconds, its temperature could be lowered almost to the freezing point For the first five minutes, the concentration of lactate in plasma remained constant The concentration in red cells and hence in whole blood rose during this period These results made it evident that lactate diffuses slowly from plasma into red cells Since at the end of the 40-second run the con centration of lactate in the extracellular fluid bathing muscle cells must have

This observation and deduction led Johnson, Edwards, Dill, and Wilson (*17*) *to study the rate of movement of lactate from plasma into red cells in vitro* Venous blood was drawn into a tube containing heparin and cooled to about 4°C The plasma, separated by centrifuging, was drawn into another tube under oil and enough lactic acid was added to bring the concentration near that found after severe exercise The plasma with admixed

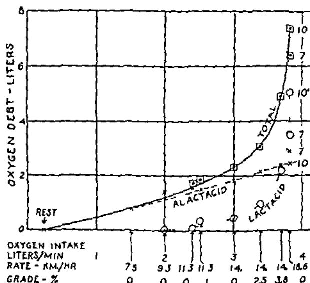


Fig 20 1 *Alactacid and lactacid debts after exercise varying in intensity and duration In this trained runner the size of the alactacid debt is proportional to the oxygen intake and amounts to about 2 5 liters at the highest level of exercise There is no accumulation of lactic acid until the oxygen intake reaches 2 liters per minute The maximum lactacid debt is about 5 liters*

lactate was then brought to the temperature of the cells and rapid mixing was effected this was completed in less than 20 seconds Portions of the mixed sample were drawn off from time to time and rapidly cooled to the freezing point after which cells and plasma were separated by centrifugation Analyses of the plasma and of the mixed whole blood were carried out for lactate, chloride, bicarbonate, and other components The results re

lactate distribution between cells and plasma *in vivo* during the first few minutes after a short bout of exhausting exercise

These observations on man and on human blood have not received much

attention from comparative physiologists It would be interesting to study these phenomena in animals, including poikilotherms Is lactate equally slow in attaining equilibrium between the red cells and plasma of other mammals and of other classes of animals? Is there any lag in the movement of lactate from muscle cells into extracellular fluid? The advantage of using poikilotherms is that exercise could be carried out at low temperatures, the experimenter would thus have more time to measure the rate of diffusion of lactate That the anaerobic production of lactate occurs in strenuously exercising fishes has been demonstrated by Black (4) Six species, after exercise of 15 minutes at 11 5 to 12°C, had blood lactates ranging from 4 milliequivalents per liter in the northern black catfish to 13 in the chub In a large crocodile some hours after capture, Dill and Edwards (7) found that the blood lactate reached 22 milliequivalents per liter

SUMMARY EXHAUSTING WORK OF SHORT DURATION

Some of the outstanding features of the fatigue resulting from all-out exercise lasting one minute or less are as follows

The lactacid debt is paid about one twentieth as fast the time required is about 1½ hours

There is also an increase in the resting oxygen consumption this is not a debt in the ordinary sense of the word

Diffusion of lactate is rapid from the tissue cells producing it into blood plasma and from thence to less active muscles it moves slowly into and out of red blood cells

FATIGUE OF EXHAUSTING EXERCISE IN WHICH ENERGY EXPENDITURE IS ONLY PARTIALLY ANAEROBIC

We have seen that the athlete who excels in sprints can maintain maximum speed for 200 meters, but not for 400 meters The record rate falls off from 9 90 m /sec in the 200 meter race to 6 02 in the 5000 meter race This transition phase extends from the sprints, which are largely anaerobic, to the distance runs, which are almost wholly aerobic

seconds, amounts to 400 ml /sec when expressed in equivalent oxygen consumption If the runner "warms up," his oxygen intake may average 3 0 liters per minute or 50 ml /sec during the race Based on these assump

tions, the rates of energy transformation during the race expressed in equivalent oxygen consumption are as follows

Total	450 ml /sec	100%
Aerobic	50 ml /sec	11
Anaerobic	400 ml /sec	89

The athlete who excels in running long distances can attain an unusually high rate of oxygen consumption Several investigators, e g, Robinson, Edwards, and Dill (24), have reported values in excess of five liters of oxygen per minute On October 23, 1954, Vladimir Kuc of the USSR established a world s record in the 5000 meter run of 13 minutes, 51 2 seconds (29) Let us assume that he ended with an oxygen debt of 8 liters and that this mean oxygen consumption during the race was 5 4 l /min Based on these assumptions, the rates of energy transformation during that record run were as follows

Total	100 ml /sec	100%
Aerobic	90 ml /sec	90
Anaerobic	10 ml /sec	10

While the above estimates are approximate, they give us a good idea of the contrast in sources of energy under these two conditions in a 20-second race, the source is 8/9th anaerobic, while in the long distance run, it is 9/10th aerobic The assumptions supporting the above calculations are based on incomplete data We do not know, for example, the total oxygen debt contracted by champion sprinters and runners in their peak performances This problem deserves further study

What difference is there between the fatigue experienced when exhaustion is reached in 90 seconds and the fatigue of a 10- or 15 minute race? In the short race, little of the lactic acid produced in the working muscles has time to reach the blood stream, after the race is over, blood lactate continues to rise for several minutes In the long race, there is time for the lactic acid to move to all tissues and so the total amount accumulated may be larger than in the short race The rates of oxygen consumption and of car- [illegible] that [illegible] minutes duration By the time these debts are paid, the resting level of oxygen consumption is attained after dashes, but not after long runs As pointed out previously, after long periods of exercise, even when the lactacid

and alactacid debts have been paid, the level of oxygen consumption sometimes is elevated for hours It seems that there is more wear and tear of body tissues in the long races—extra oxygen is required for restoring body tissues and reversing the processes of wear and tear

AEROBIC WORK

The Fuels Used

What fuels, i e, what proportions of fat, carbohydrate, and protein, are used in aerobic work? What relations exist between the reserves of these fuels and work performance? Is there a preferred fuel in aerobic work? Is there a limit to the rate of mobilization and utilization of the available fuels *other than that set by the supply of oxygen?* And what light is cast on the phenomenon of *fatigue* by the answers to these questions?

First of all, protein as a fuel can be eliminated from consideration This is the only one of the three fuels containing nitrogen Carbohydrate and fat contain no nitrogen while all proteins contain about 16 percent nitrogen Since nearly all this nitrogen is eliminated in the urine, analysis of 24 hour urine samples gives a measure of protein metabolism Physiologists long ago found that the amount of nitrogen excreted, chiefly as urea, depends on the protein intake and has almost no relation to the amount of exercise

The fuels of aerobic muscular activity must be therefore carbohydrate, fat, or a mixture of them The combustion of fat, whether in the body or the calorimeter, is associated with a ratio of carbon dioxide produced to oxygen used of 0 7 The corresponding ratio for carbohydrate is 1 0 When combustion occurs in the body, the ratio of carbon dioxide produced to oxygen used is called the *respiratory quotient* (R Q) Its value is ascertained by collection and analysis of expired air Expired air collected while lactic acid is accumulating has an R Q above that corresponding to fuel oxidation and the R Q is correspondingly low in air collected while lactic acid is being removed Hence, in order to interpret directly the R Q in terms of used fuels, it is best to determine it when a steady state has been attained in respect to lactic acid level Under these circumstances, it is found that the R Q in easy work is about 0 8, i e, the same as in rest As the intensity of the work increases, the R Q approaches unity In other words carbohydrate *is the preferred fuel of strenuous muscular activity*

Work Performance and the Fuels Used

The relation between the reserves of fat and of carbohydrate and work performance has been demonstrated in exercise experiments in man and in dogs Balke and his associates (1) have found that in work calling for about ¾ths the maximum attainable oxygen consumption, exhaustion is reached

in from 30 to 60 minutes Lactic acid does not reach a high level, but blood sugar drops Balke interprets his experiments as proof that fat cannot be mobilized fast enough for such work and that exhaustion depends on the depletion of available carbohydrate At lower intensities of work, Dill, Edwards, and De Meio (8) have found that fat can be mobilized and work can be continued after the R Q has dropped to 0 73, at which level the fuel is 90 percent fat In one such experiment, we observed the R Q and blood sugar during a period of 24 hours, including four bouts of work, each lasting two hours The subject began in the fasting state and had nothing to eat until the experiment was concluded The mean R Q 's in the successive four work periods were 0 84, 0 79, 0 78, and 0 73 We also were interested in learning to what extent the injection of adrenaline influences carbohydrate utilization The results, shown in Table 20 2 and illustrated in Fig 20 2,

TABLE 20 2 Influence of Adrenaline on Carbohydrate Utilization

Experiment	Carbohydrate Used, g In Each 2 hr Work Period I	II	III	IV	Total
Control	87	70	68	21	246
Control	92	67	57	21	237
Control	93	61	51	15	220
Mean of controls	91	66	58	19	234
Adrenaline	95	107[a]	107[a]	37[a]	346
Increment in carbohydrate used		41	49	18	
Adrenaline	88	98[a]	97[a]	32	315
Increment in carbohydrate used		32	39		
Adrenaline	97	74[b]	72[b]	29[b]	262
Increment in carbohydrate used		8	14	10	
100 grams glucose each period	122	126	116	93	457

[a] Adrenaline intramuscularly, 1 mg after 1/2 hour of work
[b] Adrenaline intramuscularly 0 5 mg after 1/2 hour of work

proved that adrenaline increased the rate of utilization of carbohydrate and resulted in a total utilization in the work periods of from 262 to 346 g as compared with 220 to 246 g in the control experiments In another type of experiment, Christensen (5) has shown that when the carbohydrate intake is high, the capacity for work performance on the bicycle ergometer

low carbohydrate diet
work of a grade which
breakdown because of

stiff and sore joints On a high fat diet with other conditions unchanged, exhaustion forced a halt after 90 minutes of work Hypoglycemia and subjective sensations indicated that the demand for carbohydrate had become acute The administration of glucose brought relief promptly, within a few minutes the subject was able to resume work

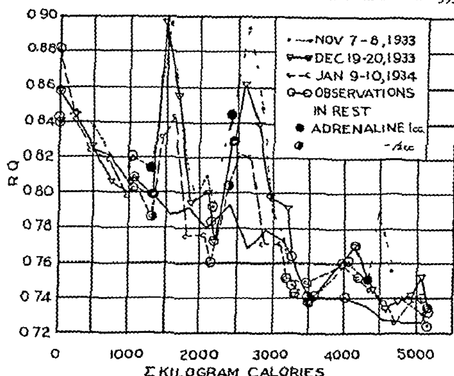


Fig 20 1 *Respiratory quotient (R Q) in relation to adrenaline injections in a trained athlete In all experiments periods of rest alternated with work as follows*

Rest	*1 5 hrs*	*Work*	*2 0 hrs*	*Rest*	*11 5 hrs*
Work	*2 0 hrs*	*Rest*	*1 0 hrs*	*Work*	*2 0 hrs*
Rest	*1 0 hrs*	*Work*	*2 0 hrs*	*Rest*	*1 0 hrs*

The heavy line represents control experiments During the expenditure of 5000 calories of reserve energy the R Q in work drops to about 0 73 In the early work periods the increase in R Q after adrenaline is large in the final work period, small

Work Performance of Dogs

Observations on the capacity of dogs for running on the treadmill bear out the same principles Our dog Joe, for nine years an active member of the staff of the Fatigue Laboratory loved to run on our motor-driven tread mill If it was started when he was within hearing, he rushed to it, jumped on, and ran until exhausted In one series of experiments reported by Dill, Edwards, and Talbott (9), the run began either after a 36 hours fast or 1 hour after a heavy carbohydrate meal In the first case, no food was given and exercise was carried on to exhaustion, in the second case, fuel in the form of a glucose sucrose candy was supplied at intervals In each case, the schedule called for 25 minute runs with intervening periods of 5 minutes

for drawing blood, observing rectal temperature, supplying water, and in some cases, fuel The dog ran 50 minutes of each hour, putting out in each of these experiments 142 kilogram meters (kg-m.) of energy per kilogram (kg) of body weight per minute

The energy output has been calculated from the data of Slowstoff (25) He found that the energy requirement for running on an inclined treadmill may be resolved into horizontal and vertical components For dogs weighing 12 to 14 kg, the horizontal component for each kg of body weight is 0 64 kg m per linear meter, and the vertical component, 2 92 kg m per linear meter through which his body is raised

Under these conditions the best performance recorded in Fig 20 3 when

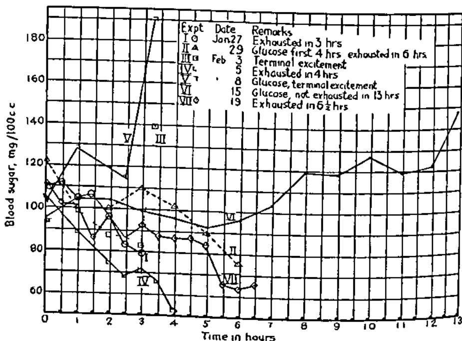


FIG 20 3 *Performance of*
rate was 142 kg m per minu..
mill for 25 minutes at a time
for blood sugar determination Starting in a fasting state and without food the

... exhausted through depletion of readily available carbohydrate

working without fuel was a run of six and a half hours to complete exhaus-

in each case, the rectal temperature remained between 39° and 40°C and

blood lactic acid concentration remained near the resting level Exhaustion came from depleted fuel in the six and a half hour run The administration of *easily available fuel in the 13 hour run resulted in twice the output of* energy without exhaustion at the end and with the blood sugar level maintained at or above the resting level The total energy outputs in these two cases were 46,150 kg m and 92,300 kg m per kg of body weight, respectively

Two other experiments, not illustrated in Fig 20 3, may be referred to briefly With the treadmill running at the same rate, our second dog, with fuel supplied, ran for nine hours By that time, she was becoming tired and her temperature had risen to 41 3°C The rate was decreased to 92 meters per minute, with the result that rectal temperature soon returned to normal and she was able to run easily for 15 more hours At the end of 24 hours, *she was not exhausted despite an energy output per kg of body weight of* 64,000 kg m during the first 9 hours and 79,000 kg m during the succeeding 15 hours, a total of 143,000 kg m In the other experiment, detailed in Table 20 3, Joe was used as a subject with the rate of work output one fourth greater than in the experiments of Fig 20 3 This higher rate of work output, 176 kg m per minute, is approximately the same as that which Rice and

TABLE 20 3 Record of a 17 Hour Run

Time (hr)	Remarks	Temperature Room (°C)	Temperature Rectal (°C)	Intake Water ml	Intake Fuel g	Blood Sugar mg/100 ml
0	Start	15 5	38 7	—	—	—
0–1	—	15 0	39 5	340	40	—
1–2	—	14 7	39 5	250	40	112
2–3	—	15 5	39 6	180	40	131
3–4	—	15 8	39 7	350	40	—
4–5	Defecated	16 0	39 6	270	40	127
5–6	Refused candy	15 6	39 9	270	0	132
6–7	Urinated	14 8	39 8	120	40	—
7–8	Defecated	14 8	39 8	30	40	120
8–9	—	14 0	39 7	180	20	111
9–10	—	12 9	39 6	50	20	—
10–11	—	15 7	40 0	105	20	107
11–12	Refused candy	14 4	39 6	215	0	—
12–13	Refused candy	13 6	40 0	100	0	103
13–14	Glucose by stomach tube	13 6	39 8	295	42	—
14–15	Glucose by stomach tube	13 4	39 7	355	50	94
15–16	Refused candy	14 0	39 7	100	0	—
16–17	Tired but not exhausted	13 7	39 5	100	0	101

NOTE Energy output 176 kg m per minute per kg of body weight, a 5 minute rest period each half hour was used for making observations and supplying water and fuel

Steinhaus (23) used Under their experimental conditions, their dogs rarely ran continuously for 30 minutes Joe, in this case, ran for 17 hours with fuel supplied and was not exhausted at the end The total work output was 150,000 kg m The distance covered was 132 km and the height of the climb was 23 km, about 2½ times the height of Mount Everest

Temperature Regulation

We are not concerned with temperature regulation in this chapter, but the limitation placed on performance by inability to keep body temperature within comfortable limits must be kept in mind This is particularly true of exercise experiments on dogs They have such a high capacity for transforming fuels that even at ordinary room temperature their exhaustion may come about directly as a result of high body temperature At very high external temperatures Dill, Bock, and Edwards (6) found that they may be unable to keep pace with man

Moderate and Light Work

Books have been written about fatigue associated with the ordinary day's work In industry, this may involve a rate of caloric expenditure of three to five times the resting level In sedentary work, it may average no more than twice the resting value So long as health is good, meals adequate, sleep sufficient, and [illegible] taken in stride [illegible] of energy at a f[illegible] day in the factory [illegible] followed by work in the garden, by strenuous games, or by dancing The policy in many industries of encouraging sports among their workmen would receive little support if the day's work produced physical exhaustion Classical methods for studying physical exercise have not been particularly fruitful in this field The fatigue of the factory worker cannot be defined in terms of lactic acid, alkaline reserve, hydrogen ion concentration, hemoglobin, or 'toxin" The problem is too subtle to yield to the physiologist's measurements of pulse rate, blood pressure, respiration, and circulation nor do the sensory tests used by psychologists give complete satisfaction The degree to which the social environment affects performance in light industrial work has been studied by Mayo (20)

Summary Aerobic Work

The fuels used in muscular activity are carbohydrate and fat In moderate work, both are used, at the highest levels of aerobic work, the fuel is predominantly carbohydrate Fatigue may be caused by exhaustion of carbohydrate reserves accompanied by depletion of blood sugar Failure of temperature regulation may cause a breakdown when external temperatures are high, especially if the rate of energy exchange is high Lactic acid does not increase in the blood in light or moderate work

PHYSICAL FITNESS

INTERDEPENDENCE OF FATIGUE AND FITNESS

In strenuous physical exercise, the degree of fatigue experienced depends on the state of fitness If a group of men, for example, climb a hill or run on a treadmill at the same pace, they can be differentiated by observations on heart rate, respiratory rate, and blood lactate Such a quantitative study of performance was made by Dill, Talbott, and Edwards (11) In a 20-minute run on the treadmill, heart rate varied from 132 to 180 respiratory minute volume from 50 to 80 liters per minute, and increases in blood lactate from 0 8 to 5 9 milliequivalents per liter

FITNESS TESTS

This topic is dear to the heart of physical educators The number of fitness tests is legion Rather than entering this controversial field, reference will be made to a number of valuable wartime studies, many of which remain unpublished A graduate student interested in this field might well analyze these reports, most of which can be obtained from the specified military sources given in the bibliography

Phillips (22) has reported a low but significant positive correlation be tween the three elements of the JCR test (jump, chin, run) and success in primary and advanced training There was no correlation between the Schneider test score and success in primary and advanced training

Graybiel and West (15) have measured physical fitness by "composite," "step," and pack tests With few exceptions, the physical fitness of enter ing students was high All had passed a screening examination designed to exclude those not meeting prescribed physiological and psychological stand ards Among those who were approved for flight training, no relation was found between physical fitness and flight performance It was concluded that it is apparently unnecessary to maintain superior levels of physical fitness during the training stages comparable studies of fitness in relation to combat performance were recommended Erickson and associates (13) demonstrated the usefulness of the treadmill as a controlled work-output device in many situations, especially in precise evaluation of physical fitness C Taylor and Franzen (27) described the 'Taylor" treadmill test of work capacity It consists of an initial run of 1 minute on a 5 percent grade at 162 meters per minute Each minute the grade is raised 1 percent until the sub ject stops from exhaustion The score is the total work output This test is only practiced in the laboratory, the same report includes exploratory studies of submaximal tests but no definitive recommendation was made This report contains an extensive bibliography H L Taylor and associates (26,28) found that subjects kept in bed for three weeks lost 15 5 percent in plasma volume while red-cell volume remained unchanged. Blood vol-

ume decreased 9 3 percent The first week of reconditioning resulted in an increase in plasma volume but a decrease in red cell volume During the subsequent five weeks' reconditioning, the blood volume and the red cell volume were restored There were major evidences of deterioration in fitness during three weeks' bed rest Pulse rates in moderate work ranged from 121 to 134 before bed rest and from 162 to 181 at the end of three weeks in bed, the mean increase being 45 beats per minute This corresponds to a drop from a good to a poor fitness score The report includes a valuable bibliography of 22 references

Kark and associates (18) used the Harvard step test and pack test in tropical and temperate field studies to evaluate fitness among troops in the United States, Canada, the Pacific, and India Analysis of the relations between individual clinical stigmata and biochemical measurements and between individual clinical stigmata and physical fitness scores revealed few significantly positive correlations Such correlations as existed had no apparent physiological explanation No support is given to the proponents of a large intake of vitamin or a low intake of animal protein

Eichna, Bean, and Ashe (12) evaluated the fitness of a group of 125 enlisted volunteers by the AGF and AAF tests, the Navy step test, and the Harvard step test None of these tests is ideal, motivation—the "will to do"—may be an exclusive determinant of fitness as scored by any one of these tests The authors consider that an officer who has worked with and knows his men is better able to evaluate their fitness than any fitness test yet devised Men strive to attain better scores on repeated testing, the competition thus aroused is an incentive to improve fitness W B Bean and 11 associates (2) employed five methods for measuring the acceptability and adequacy of rations

- Questionnaires
- Caloric intake and consumption of individual items
- Food wastage
- Physical fitness by
  - AGF battery of tests
  - AAF battery of tests
  - Harvard step test
  - Appraisal by platoon and company commanders
- Evaluation of nutritional state by
  - Clinical examination
  - Biochemical measurements

The following essential conditions were met

- Enough subjects for valid results—a battalion of 827 men plus officers
- Enough time for valid results—9 weeks isolation
- Experienced and competent testing personnel
- Military training resembling combat

Significant conclusions were

Medical status No vitamin deficiency disease appeared General health was excellent No ration imposed any physiological handicap

Biochemical status Within the limits of time of this test, variations observed

•

of ration The only possible conclusion is that all of the rations *when eaten under the circumstances of this test* were adequate for maintenance of physical fitness and activity for troops in arduous training

This report contains the greatest body of reliable diversified data on physical fitness of troops during training Incidentally, the study is a significant contribution to high altitude physiology The troops had been previously conditioned at Camp Carson, 6100 feet The study itself was conducted at altitudes ranging from 8700 to 9000 feet

In a later report, Bean and associates (2) critically reviewed the AGF and AAF batteries of tests, the Harvard step test, and the Navy step test, all of which were employed in numerous investigations in their laboratory, now called the U S Army Medical Research Laboratory They reached the following conclusions

None of the tests is satisfactory for discriminating among degrees of individual fitness This fault arises from

Failure to test chief components of fitness
Inadequate scoring system
Abnormal distribution of performance achievement and/or score
Lack of reproducibility
Inability to control or measure motivation
Inequality of stress on all subjects
Failure to consider physiological cost or postexercise conditions
Presence of test components where readily acquired skills permit subjects to 'beat the test'
Failure to consider environment or physique in scoring systems

On the other hand, it was concluded that

Several of the tests are satisfactory as gross measures of fitness and permit satisfactory comparison of groups
A battery of fitness tests gives a better measure than a single test
Performance tests, when competition is aroused, serve as incentives to improve fitness

The authors further concluded that experienced line and noncommissioned officers, familiar with their men, can appraise fitness as well or better than is done by existing fitness tests They recommended that a far reaching program of basic investigation in physical fitness and reliable methods for testing be included in the plan for postwar medical research for the Army

Fitness of American Youth

If one judges by health and life expectancy, the American youth is more fit physically than ever before If one judges by certain physical fitness tests, our boys and girls are woefully unfit The pros and cons were weighed in the *U S News and World Report* for August 2, 1957 (16) It does appear that many of our youth are softer than ever before and that this reflects over attention to highly organized sports for the few and failure to provide physical training and sports for the many who are not of first team caliber This last topic was given forceful attention recently by Morris (21) The President's Council on Youth Fitness has held two conferences on the fitness of American Youth, the first at Annapolis in June, 1956, and the second at West Point in September, 1957 (14) Among the recommendations of the second conference were several dealing with research In particular, it was recommended that immediate concentrated research be directed towards

Scientific testing and evaluating of human fitness, with a view to developing simple but effective methods and standards for general use in measuring fitness

Measuring on a scientific basis the contribution of various sports, exercises, and activities to the development and maintenance of fitness of the whole individual as well as in particular elements for both sexes at different age levels

Discovering the reasons for lack of participation in effective youth fitness programs and the factors which motivate children as well as parents to participate

Making an inventory of facilities and appraising their use for youth fitness programs

Assessing of trained personnel and development of methods for enlisting and training necessary additional leadership

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21 LUCIEN BROUHA

Training

SUMMARY

Many physiological responses are altered by training In general the improvement in each bodily system is of the order of 25 percent or less, but when taken together all the effects may result in an improvement of total performance which may be as high as 100 percent and occurs in both the magnitude and duration of the work which can be done The following is a list of changes produced by training which have thus far been studied

1 *Increased strength of the muscles and improved neuromuscular coordination*
2 *Greater mechanical efficiency as measured in terms of lower oxygen consumption for a given amount of work*
3 *Greater maximum oxygen consumption*
4 *A higher maximum cardiac output with less increase in pulse rate and blood pressure during submaximal exercise*
5 *More economical ventilation during exertion, and a greater maximum pulmonary ventilation*
6 *Lower blood lactate for a given amount of exercise, i e, capacity to perform more work aerobically, and ability to push self to a higher blood lactate before exhaustion, i e, capacity to perform more work anaerobically*
7 *Quicker recovery in pulse rate and blood pressure after submaximal exercise*
8 *Better heat dissipation during submaximal exertion*

INTRODUCTION

People who exercise regularly are capable of greater efforts and resist fatigue better than sedentary individuals Progressive changes take place in

many physiological functions and through these processes of adaptation, known as training, the ability to do muscular work improves Understanding of what happens during training is one of the fundamental problems of th physiology of exercise Information has been obtained by comparing th physiological reactions to exercise of trained athletes and untrained indivic uals This method shows how various degrees of efficiency are achieved b

to the physiological functions showing the most important changes as a re sult of training These changes will first be summarized They all contribut to an increased capacity for muscular activity and include (1) greate strength of the muscles, (2) better neuromuscular coordination reducing th energy requirements for a given amount of external work, (3) improve cardiovascular functions leading to a better supply of oxygen to the workin muscles and to a greater amount of blood available for heat dissipation

intensity of conditioning exercise specificity of training, and effect of indi vidual differences

GENERAL EFFECTS OF TRAINING

Effect of Training on the Muscles

Repeated muscular work produces an increase in the size of the skeleta muscles It is generally agreed that muscle hypertrophy is not due to the formation of new fibers Fibers that are small from lack of use are present in every muscle and they develop to full size when regular exercise puts a greater demand upon the muscle The increase in size is accompanied by the development of more capillaries in the trained muscle (10) It seems that exercises of strength produce mostly a hypertrophy of the fibers, whereas exercises of endurance increase the number of capillaries The increase in size of the fibers and in the number of capillaries is accompanied by a gain in strength This is characterized (1) by the ability to produce more power ful contractions i e, gain in power, (2) to repeat contractions more rapidly i e, gain in speed, and (3) for a longer period of time, i e, gain in endur ance Strength of the muscles can be developed only by exercising them against gradually increasing resistance such as pulling or pushing springs lifting weights and/or moving the body at increasing speed The gain in strength is more striking than the hypertrophy of the muscle it is possible to increase the power of muscles three times or more without a proportional increase in volume

The final result of training on the muscles varies with the kind of exercise performed, the degree of repetition, speed, duration, and intensity of contractions Individual factors are also involved, and two subjects following the same training program may not necessarily develop their muscles in a similar manner Gain in absolute strength, that is the power of one contraction, does not always mean a greater endurance A strong man such as a weight lifter can perform work against greater resistance But a man with less powerful muscles such as a miler can produce a much greater amount of work over a given period of time Increase in speed and endurance, which is out of proportion with the gain in size, suggests that the quality of muscular contraction is improved by training What takes place when training produces growth, gain in strength, and endurance in the muscles is not fully understood as yet The improved vascularization in the trained muscles makes more fuel and more oxygen available for the contraction processes Furthermore glycogen, phosphocreatine, and myoglobin are stored and available in larger quantities in the muscles themselves

Another factor very likely improved by training is the transmission of the nerve impulses to the motor units The result is that a given impulse produces the simultaneous contraction of a greater number of muscle fibers so that the muscle can be used in its entirety without any idle fibers left and with a maximum strength Whether the greater muscular efficiency obtained by training is due primarily to chemical factors in the muscle, to an improved blood circulation, to a more efficient action of nervous impulses, or to other causes is still debatable Further research is needed to elucidate the mechanisms which lead to an increase in muscle power and endurance through training

EFFECT OF TRAINING ON NEUROMUSCULAR COORDINATION

Training improves the precision and the economy of any motion or sequence of motions involved in muscular activity Unnecessary static and dynamic muscular contractions are progressively eliminated, more complete relaxation of the antagonist muscles is achieved, the motions become more simple and more automatic because reflexes replace in part voluntary action The final result is that for a given performance a decrease in energy expenditure occurs which can reach one quarter of the total energy needed before training The greatest differences are found among beginners who have to learn the particular motions involved in a given exercise and have to acquire the skill to perform them efficiently In athletes with several years of practice this particular effect of training is less noticeable because, even when untrained for a new task, they possess the skill to control their motions

Qualitative and quantitative information on the effect of training on neuromuscular cooordination can be obtained by using a "force platform" such as the one designed and used by L Lauru (9) Measurements are made through sensing elements which are piezoelectric quartz crystals developing

a dielectric polarization when they are compressed The compression of the quartz crystals is only a few microns and forces from a fraction of an ounce to several tons can be measured A triangular and very rigid platform permits the location in space of the various quartz crystals so that they can simultaneously pick up force phenomena arising vertically, frontally, and trans

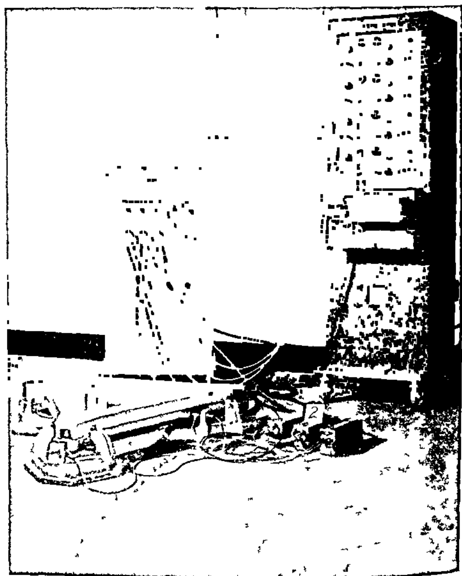


FIG 21 1 1
sensing element
channel amplific
tals is fed through the electrometer bridges to the Sanborn for amplification and recording

versally These are amplified and recorded (Fig 21 1) With the subject on the platform, the whole system is balanced to zero As soon as the subject moves, the piezoelectric quartz crystals registering *in the three dimensions* are submitted to pressure variations The pressure variations are proportional to the forces applied to the body by the neuromuscular system, and these forces are a measure of the effort required to perform a specific exercise

Fig 21 2 shows a record obtained for the three components vertical,

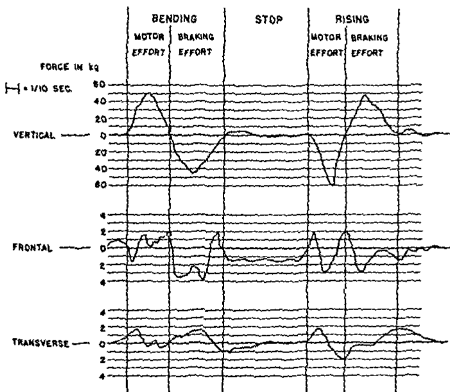


Fig 21 2 *Forces involved in bending the knees and straightening up as re* co ... *form in the vertical frontal and transverse compo* ne ... *a diminution of pressure and* b ... *The force time* ... tion (4)

frontal, and transversal when the subject *bends the knees,* ... straightens up to an upright position It may be seen that bending involves active forces from muscles displacing the body downwards and braking forces from the antagonist *muscles* which control and finally stop the mo- t ... involves an active effort and a braking effort ... motion the apparatus ...

the elements of the motion studied. It is possible to demonstrate by this method of analysis that, of the various motions capable of producing the same final result, some require less expenditure of bodily forces than others. For any mechanical work performed, there is one motion which is the most efficient and which is physiologically the most economical as shown by the lowest oxygen consumption (4). By training, neuromuscular coordination is improved until the most economical motions are achieved in a given subject. Furthermore the most economical speed for repetitive motions can be determined. It is the one at which the various muscles are functioning with the least force. This economical speed of repetitive motions is increased quite markedly by adequate training.

When the various motions performed in an exercise are studied, a complex curve is obtained in which the amplitude of the recorded forces is proportional to the corresponding efforts. As an example, Fig. 21.3 gives three diagrams showing the changes that occurred in an athlete doing a broad jump from the platform before and after training. The upper diagram rep-

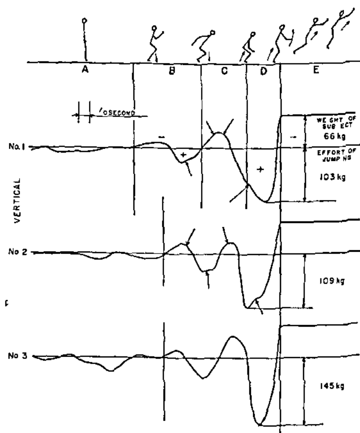


Fig. 21.3. Tracings of the vertical component for a broad jump performed by the same subject before and after training (9).

resents the efforts that are produced before training The jumping effort or "push" against the platform reached 103 kg and the tracing shows, as indicated by the arrows, hesitations and lack of cooordination during the preparatory motions In the second diagram the pressure of jumping increased to 109 kg, leading to a better performance but coordination defects were still present The lower diagram shows the results of further training The push against the platform has been increased to 145 kg, and maximum performance is reached resulting at least partially from an improved coordination and a smoother sequence of motions

Many problems in this field remain unsolved and few precise data are available on what training methods are best to improve neuromuscular coordination and develop skill related to specific motions used in various kinds of exercise and sports

EFFECT OF TRAINING ON THE CARDIOVASCULAR SYSTEM

With training the heart becomes more efficient and is able to circulate more blood while beating less frequently (6) Contraction of the heart becomes more powerful, thus it empties itself more completely at each systole, and stroke volume and cardiac output are increased For a standard amount of work the heart rate becomes slower as training progresses (Fig 21 4) These heart rate changes indicate a decreasing load on the cardiovascular adaptation to exercise Slow heart rates are observed even at rest and it is not exceptional for the resting pulse rate to be reduced by 10 to 20 beats per minute between the beginning and the end of a training period This greater efficiency of the heart enables a larger blood flow to reach the muscles, insuring an increased supply of fuel and oxygen and permitting the individual to reach higher levels of performance

Blood pressure is also influenced by training Prolonged effort in the untrained subject leads to a progressive fall of the systolic pressure which indicates approaching exhaustion The appearance of this phenomenon is greatly retarded by training so that heavy work can be maintained for a longer time without appreciable change in the blood pressure (5)

Training improves the cardiovascular recovery processes after exercise stops the better trained the individual, the sooner his heart rate and his blood pressure return to the pre exercise level (Fig 21 4)

Blood distribution is also affected by training, and although experimental data are still scarce the changes that occur may be as follows Training reduces the amount of oxygen needed by the working muscles, and consequently the necessary blood flow to these muscles is reduced Under these conditions for the same cardiac output more blood remains available for the other organs of the body after training than before This process may well explain the fact that albuminuria, for example, as a consequence of heavy

exercise takes place in warm surroundings Training in itself improves the capacity to exercise in heat because so long as less blood is needed by the muscles to perform a given amount of work more blood is available for heat dissipation in the skin, and body temperature remains lower

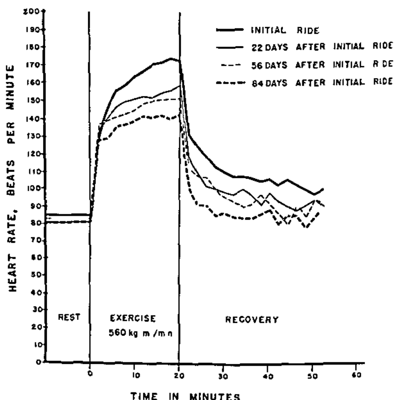


FIG 21 4 *Effect of training on heart rate for a standard*

EFFECT OF TRAINING ON THE RESPIRATORY SYSTEM

oxygen consumption and carbon dioxide production decrease progressively for the same work load to a minimum level as training progresses Furthermore, at high work levels, for a given minute volume of air, oxygen intake

the respiratory muscles themselves, like the other muscles, improve their efficiency during training This process involves not only the diaphragm but also all the thoracic and abdominal muscles that are involved in heavy breathing during hard exercise Changes in pulmonary ventilation per minute are associated with a decrease in rate and an increase in depth of breathing In the trained subject even at rest the depth of breathing is greater and the respiratory rate may fall from about twenty to about eight breaths per minute During heavy exercise the improvements due to training are quite striking and the diminution of the respiratory minute volume can reach up to 25 percent for a given work load

Effect of Training on Aerobic and Anaerobic Performances

Because of all these changes the amount of muscular work that can be performed with an adequate supply of oxygen becomes greater as training progresses Therefore aerobic processes of muscular contraction are sufficient to perform higher levels of work with little accumulation of lactic acid in the blood, and anaerobic processes of muscular contractions are not necessary until heavier exercise is performed A balance between aerobic and anaerobic processes can be maintained in a steady state at a higher level of work, with a constant concentration of lactic acid in the blood Greater maximum efforts can be produced because contracting an oxygen debt begins only after a much higher level of oxygen consumption has been reached and lactic acid starts accumulating at a heavier work load and builds up less rapidly

It may also be that training increases the *capacity* for anaerobic work The highest concentrations of blood lactic acid have been observed in trained subjects pushing themselves to exhaustion (11) Attempts to explain this phenomenon by an increased alkaline reserve have not been substantiated Alteration in the pyruvate-lactate equilibrium could account for the higher lactate observed after training (8) but assuming that high lactic acid levels do represent greater anaerobic work we feel that one important factor in reaching these high values is the determination and motivation of the individual With training he becomes more and more accustomed and willing to push himself to his limit He progressively learns to endure discomfort and to increase the duration and intensity of effort during which he utilizes his anaerobic capacity Therefore he succeeds in performing more anaerobic work and builds up a higher concentration of lactic acid The relative importance of psychic and physiological factors in reaching exhaustion is worth further investigation

SPECIAL ASPECTS OF TRAINING

Effects of Duration and Level of Conditioning Exercise

In addition to the neuromuscular effect of training resulting in lower oxygen requirements, the combination of the circulatory and respiratory

changes leads to more efficient transport of oxygen to the active muscles Within limits, the concentration of lactic acid in the blood depends on the adequacy of oxygen transport and utilization Consequently, taken with other physiological criteria it can give information on the functional value of

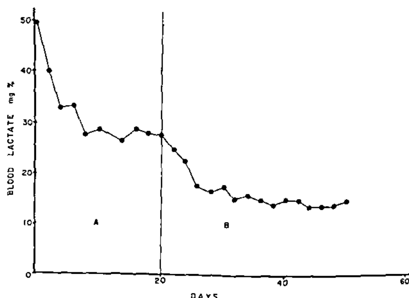


Fig 21 5 *Progressive decrease of blood lactate for a standard amount of exercise running on a treadmill at 7 m p h for 10 minutes During the first twenty days (A) training consisted in running daily on the treadmill for 20 minutes at 7 m p h A steady level of blood lactic acid is reached around 28 mg percent During the following thirty days training is increased to running at 8 5 m p h for 15 minutes daily (B) Blood lactic acid decreases further and a new steady level is reached around 15 mg percent after the standard test (7)*

the respiratory, circulatory, and muscular systems, and on the effect of training Various series of personal experiments can be summarized as follows Very rapidly after regular training begins, the heart rate, respiratory rate, and blood lactic acid decrease during performance of a standard exercise test After a given training program has been followed for a few weeks, no further improvement takes place and a steady level of training is reached which varies with the individual At this point if the *duration* of the daily training is increased, the work rate remaining the same, no additional improvement is achieved On the other hand if the *work rate* is increased, the standard test can very rapidly be performed more efficiently as shown by lower heart

acid (Fig 2

of training

increase in work rate until a state of maximum training is reached (7)

When training involves a moderate level of activity, it can be interrupted for as long as a week or ten days without any sign of deterioration during a standard exercise test On the contrary, when the exercise is heavy interrupting training for no more than four to six days is immediately followed by a decrease in efficiency as indicated by faster heart rate and higher concentration of lactic acid in the blood (Fig 21 6) Here again many problems are

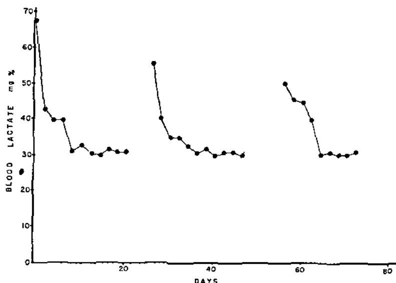


FIG 21 6 *Effect of stopping exercise for a few days during a training period for heavy exercise The test consists in running on the treadmill at 7 5 m p h for 10 minutes Daily training at 8 5 and 9 m p h for 5 to 10 minutes The dotted lines indicate two periods during which no exercise was performed* (7)

intensity and duration of daily exercise (3)

SPECIFICITY OF TRAINING

General physical training increases the efficiency to perform any kind of muscular activity provided the work load is moderate For heavy exercise when an individual is trained for a specific activity, he is more efficient and capable of doing more work of that particular nature than when he performs any other kind of exercise The simple observation of athletes involved in seasonal activities shows clearly that if an individual completes a training period for a given sport in excellent condition and starts immediately to practice another sport, a certain time will elapse before he reaches his maximum efficiency in this other form of muscular activity This is true even

when the subject is a qualified athlete in the two sports so that no learning process is involved and skill improvement is a very minor factor. Experiments were undertaken in an attempt to elucidate this problem, and the performances of highly trained athletes, including varsity oarsmen and cross-country runners, were studied. A first test consisted of a treadmill run at 7 m.p.h., grade 8.6 percent, for five minutes. The second test was made in a rowing tank at 22 strokes per minute for four minutes and 30 strokes per minute during the fifth minute. Heart rate was recorded and a blood sample was taken five minutes after the end of exercise for lactic acid determination. All subjects were able to complete the two tests, which for them were submaximal work. The results were remarkably constant and showed that for the two tests, running and rowing, the cardiovascular reactions were similar for all subjects. It seems that for these experimental conditions the responses of the circulatory system of an athlete to heavy muscular work remain the same regardless of previous training and the nature of the exercise performed.

On the other hand, blood lactic acid varied markedly according to the kind of test performed and to the nature of the preceding training. It was found that for a practically identical cardiovascular reaction a runner accumulates more lactic acid when he rows than when he runs, and an oarsman reaches a higher lactic acid level when he runs than when he rows. Therefore, physical training has a definite specific action in relation to lactic acid production during heavy muscular work. The final result is that the maximum lactic acid saturation is reached more rapidly and subjectively

is trained. Since in the above experiments the cardiovascular reactions were constant, it appears that the specific training process occurs at least partly in the muscles themselves (2).

Individual Differences and Training

In healthy individuals, regardless of inborn capacities, sex, or age, modifications in physiological efficiency can be produced under controlled conditions of physical training. The homeostatic mechanisms become more efficient so that in response to an equal amount of work the displacement

work have a considerable range of values. Consequently when an individual improves his physiological mechanisms by appropriate training, he will

annot go and

onstrates this

The amount

of daily exercise that is needed to reach and maintain physical efficiency at

the highest attainable level is still determined mostly by observation or empirical methods Experiments show that a daily amount of practice which is suitable for an individual is either too much or too little for others They also demonstrate that, regardless of the physical capacity of a given subject,

TABLE 21 1 Examples of Variations in Physiological Measurements Before and After Physical Training in a Group of 21 Oarsmen

Treadmill Test 5 min run at 7 m p h grade 8 6%

		Averages
Maximum pulse	Before training 191	Range 172 205
	After training 177	Range 158–195
Maximum blood lactate	Before training 105	Range 53 166
	After training 80	Range 41 142

Subject	Maximum Pulse During Run — Before Training	After Training	Maximum Lactate mg /100 cc of Blood — Before Training	After Training
Cu	172	158	68	41
Mar	173	170	141	83
Er	180	164	102	73
Gi	185	172	112	64
No	185	172	53	50
Ri	190	170	84	70
La	190	180	117	77
Cha	190	178	77	77
Wh	190	172	108	62
So	192	174	130	95
Ch	193	186	74	74
Ly	195	180	78	75
Pr	195	195	166	142
O	195	176	149	90
Fi	195	192	133	110
Eu	196	182	91	59
J	196	180	93	89
Br	196	168	121	95
Ma	200	180	74	68
Sn	204	178	103	89
An	205	186	122	106

SOURCE Data from "Variability of Physiological Measurements in Normal Young Men at Rest and During Muscular Work" by L Brouha and B M Savage *Revue canadienne de Biologie* 1945 4, 140

there is a level of exercise which frequently repeated will lead to chronic fatigue and staleness This state is characterized among other factors, by higher heart rates and lactic acid concentrations for a standard exercise than were previously observed during the training program

The wide individual differences in physiological adaptability to training are striking It should be fully realized that although anybody can improve his working capacity by training, outstanding athletic performances are attainable only by a comparatively small number of individuals whose physiological mechanisms are highly efficient and precisely integrated To become a champion implies innate capabilities, mental and physical, that are developed to a superior level by adequate training and permit outstanding performances in a particular field of athletic activity The variation in capacities and the limitations of any individual who goes into training should be known by those who are responsible for directing physical education and sports activities

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PART III

Maturing and Aging in Relation to Exercise and Sports

22

ANNA ESPENSCHADE

Motor Development

SUMMARY

It is the purpose of this presentation to trace the course of development of motor behavior from childhood to maturity The report is limited to the area of postural locomotor development, and considers specifically balance, coordination, strength, and the fundamental motor performances running, jumping, and throwing

Consistency from individual to individual of pattern or sequence of development of gross motor behavior in infancy is indicative of the dominant role of phylogeny Wide individual differences in rate of development and in quality of performance become evident in early childhood

The close relationship of certain motor characteristics to size, body build, and maturity level are discussed Many different studies have shown that physical size and gross motor performance in childhood and afterwards increase together, but there is little evidence on this subject for infants Studies of the relationship of age, weight, and height to measures of strength, running, jumping, and throwing have been made on children, and where age is held constant, weight and height are found to be related to all these events for boys from 10–18 and for girls 10–13 Classification schemes based on age, height and weight are practical means of grouping children for physical activities, but these have been found lacking as indicators of maturity level The Sheldon method of body typing has recently been extended into preadolescence, and studies relating physique to gross motor performance of boys indicate that body form is an important factor in physical strength

Boys continue to improve in strength until they are 18 years or older, but girls taper off after the 14th year Strength is so closely linked with individual growth patterns that it may in itself be regarded as an indication of puberty and as a secondary sexual characteristic Balance plays a conspicuous role in

postural locomotor development, but a great deal of research is needed in this area before definitive statements can be made as to the relationship of balance to age and other motor abilities

Coordination, which is characterized by easy movements which are well timed and controlled, is not readily measured objectively Evidence from the Brace test indicates that boys are especially superior in agility measures, older girls are less able than younger ones to do some of the stunts of the test but in static balance, older girls are superior The pattern of development in coordination in boys differs from that in strength.

Running, jumping, and throwing are common elements in active games, and thus performance in these activities may be used as indications of motor ability Scores in these activities for boys increase from childhood through high school Those for girls increase only through the 13th year The latter findings may well be due to cultural influences and personal interests, experiences, and attitudes

Growth curves in selected motor skills tend to show fairly steady growth in boys and girls aged 5 to 16 or 17 years However, a number of studies show that rate of change varies at puberty and is not the same for all measures Further investigation should contribute substantially to the understanding of motor development from birth to maturity

Many disciplines have contributed to our present knowledge of child development Studies of physical growth, of health and disease, of intelligence and school progress are chronologically the oldest, those of personality and social adjustment more recent Longitudinal studies, in which the same group of children has been followed for a number of years, have made important contributions to the understanding of individual as well as of group development Included in these studies, and in many isolated investigations as well, are data on motor development and it is with this aspect that the present report is principally concerned

Because all aspects of growth are interrelated, no single factor can be studied in isolation Changes in motor behavior may be brought about by developing neural structures, by changes in bone and muscle, by hormonal or vascular maturation and by experience or training Certain patterns laid down by heredity are not subject to marked modification and this is particularly evident in early motor development However, it is more profitable for an understanding of these phenomena to ascertain the direction of growth in specific activities, and fluctuations and rate of improvement in large samples than to attempt to separate innate and environmental influences

In the area of postural locomotor development it is possible to identify common patterns or sequences of behavior, changing rates of growth from birth to maturity, and interrelationships between structure and function

The number of variables affecting behavior in this area increase with age and the data available at present are insufficient to give more than a very general picture

INFANCY

The rate of neuromuscular maturation in infancy is so great that marked changes in behavior may be observed in relatively short periods of time The studies of Gesell (23), Bayley (4), Shirley (52), and McGraw (36) all make important contributions to knowledge in this area The influence of hereditary factors is clearly evident in this period Gesell (23) has noted that behavioral organization begins in the fetal stage and proceeds in an orderly course Patterns develop in a cephalocaudal direction, from proximal to distal segments, and from fundamental to accessory control

The specific neuromuscular developments involved in the acquisition of a sitting posture, of crawling and creeping behavior, and of swimming movements have been reported in detail by McGraw She has identified four outstanding periods in the first two years of life which relate growth in neural structures and in function

> The first period covers approximately four months and is marked by a diminution of the atavistic reflexes and rhythmical movements characteristic of the newborn The second period ranges from about four to eight or nine months and is characterized by the development of deliberate or voluntary movements in the superior spinal region and by comparatively reduced activity in the region of the pelvic girdle and lower extremities The third period is characterized by increasing control of activities in the inferior spinal region and represents the age range from eight to fourteen months The fourth period covers the remaining ten months and is marked by rapid development in associational processes, simple or direct conditional and symbolic associations, including language [36,362]

Shirley's study (52), in which she observed systematically the same infants over a two-year period, demonstrated the orderly sequence common to all in locomotor development Bayley's observations (5) of a group from birth to maturity traces gross motor development from birth to seven years Emphasis in the early years is on the study of postural locomotor control and the development of manual coordination Continuing development in postural locomotor control is studied in older children by measures of balance, hopping, jumping, and throwing

The consistency of early behavior patterns from infant to infant is evidence of phylogenetic determination Individuals differ markedly in their rate of development, however, and rate may be regarded as an ontogenetic characteristic That this rate may be influenced to some extent by environmental conditions has been shown by Dennis and Dennis (17) who demonstrated that restriction of opportunity between the seventh and fifteenth

months of life may retard development, and by Smith (54) who reported the influence of severe illness during the first two years of life Socioeconomic status of parents is not significantly related to motor development in the early years, however (7)

CHILDHOOD

By the latter half of the second year the child may be expected to have sufficient control of locomotion to achieve some independence of action The rate of growth gradually decreases but new movements become possible progressively It will be of interest to note the order of development and the normal timing of a few of these which clearly demonstrate the continuing motor sequence (5)

Jump off floor both feet together	28 months
Jump for distance from 26 cm height	37 3
Stand on one foot alone	29 2
Hop (less than 2 meters)	49 3
Throw into basket (1 5 meter distant)	61 5

Gutteridge (25) studied the motor development of children as shown in a variety of activities Ratings of the proficiency of children ages 3-7 years in these activities were made by trained observers The following are of importance in postural locomotor development

	By 5 Years	*By 7 Years*
Jumping	58%*	84%*
Hopping	33	84
Skipping	14	91
Galloping	43	92
Throwing	20	74

* % of group rated proficient

Boys excelled in jumping and throwing girls in hopping skipping and galloping

ADOLESCENCE

body build An understanding of physical growth in adolescence is fundamental to the study of motor development

The sequence of growth changes at puberty may be distinguished by acceleration of growth in height, weight, and breadth in the early phase, followed by rapid deceleration in the final stages as adult stature is attained At

the same time, sexual characteristics—axial and pubic hair, breast development (especially in girls), facial hair and voice changes in boys, and the sexual organs themselves, develop rapidly The appearance of the first menstruation indicates puberty in girls but no such specific landmark is available in the case of boys Recent studies have used the period of maximum growth in standing height as an indication of physiological maturity since it can be reliably identified in both sexes This age may be regarded as at least a rough indicator of sexual maturity because it correlates 706 to 754 with the advent of menarche (53) Although no similar figures are available for boys, a comparable degree of relationship almost certainly exists

Since the age of maximum growth cannot be identified with certainty until well after this period has passed, other means of assessing maturity in boys have been sought Crampton (14) in 1908 classified boys into prepubescent, pubescent, and postpubescent groups on the basis of ratings of pubic hair changes His method has been used by many investigators A somewhat finer classification has been more recently proposed by Greulich, *et al* (24) Five categories of maturity groups are identified through examinations of the developmental stage of hair on various parts of the body and of the size of the sexual organs themselves Studies of skeletal development and of endocrine substances in urine confirm the fact that these five groups represent successive stages of maturation These latter methods of study (skeletal and endocrine) may be used as reliable indicators of maturity in both sexes but due to the expense, time, and difficulty involved may not be practicable in most situations

It has long been recognized that the adolescent growth spurt in girls precedes that in boys Average age of maximum growth for girls in the Harvard Growth Study (53) was 12 56 years, for boys 14 89 years In the California Adolescent Study, these average ages were approximately six months earlier But the range of individual differences is more important in understanding children than is an average Slightly over three percent of the girls in the Harvard Study showed maximum growth at 10 5 years, while four and one half percent did not reach this point until four years later The range in boys was four years also with the earliest three percent at 13 0 years and the latest at 17 0 A few individuals of each sex were still more unique in their timing and fell outside the ranges noted If adolescence starts with acceleration in physical growth and ends with attainment of mature stature, it must include as a minimum *the years 8 0–19 0 in girls, 9 5–22 0 or 23 0 in boys*

Increase in stature is only one measure of adolescent growth Standing height may be thought of as made up of two principal components, sitting height and leg length, and the proportion of each of these in the total changes Early adolescence is a time of relative long leggedness, especially in girls As maturity is approached, sitting height accounts for slightly over half of stature in most individuals

Hip width is both relatively and absolutely greater in girls than in boys at

all ages Both sexes show continuing growth in this measure Shoulder width is greater in girls than in boys in childhood but boys surpass girls at about thirteen years and continue to increase markedly in this aspect of growth so that at maturity, masculine shoulders are wider than hips The reverse is true for girls Shoulder development occurs later than leg and hip growth

Because girls mature earlier than boys, they are on the average actually taller than boys from 10 5–13 years They are also slightly heavier, have broader hips, and broader shoulders Weight gain of girls in adolescence tends to be associated with increased subcutaneous tissue, but this is less true in boys In the latter, increased muscle bulk seems to account to a great extent for the increase in weight

When growth curves in height for large numbers of children are drawn according to chronological age these individual differences, and indeed the rapid rates of growth in early childhood and again at puberty, are somewhat obscured and growth appears to take place at approximately a steady rate

this time, however

INTERRELATIONSHIPS OF SIZE AND BUILD WITH MOTOR PERFORMANCES

Many studies have shown that there is a close relationship between physi

not confirmed by Peatman (43) Shirley also noted that good muscle development seemed to advance motor behavior

Extensive studies of the relationship of age, weight, and height to measures of strength, of running, jumping, and throwing have been made on children of school age

cant correlations with

boys from 10–18 years (

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Correlation

for boys in junior high school were found to be 73 by Dable (16) In the California Adolescent Study, classification of boys in Grades 8, 9, and 10, respectively, correlated with maturity 54, 62, and 50 (21) In these same cases over a wider age range physiological maturity was found to correlate 82 with chronological age and 89 with skeletal age. Tables showing the

range of physiological maturity in each classification letter in junior and senior high school boys have been published by Espenschade More recently, the relation of the McCloy[1] classification scores to physical performance has been studied by Nevers (41) Both reports show that there is marked overlapping of maturity groups in the same classifications Jones (30) comments that due to differences in body build there are exceptions to the 'big and strong' classification, as a few boys are of large size but poorly muscled whereas others are small but mesomorphic and strong

It seems reasonable to believe that some scheme of body typing may weight more accurately the various factors of size and maturity which influence physical performances Some progress has been made toward systematic classification of 'types' in childhood The seven channels of the Wetzel grid make provision for varied body types and may be used as a means of grouping (56) A scale for androgeny, the sex appropriateness of the body, has been developed by Bayley and Bayer (6) and may be of especial value in the study of physique and personality in adolescence No studies have been made which relate these body classes to motor performance The Sheldon (51) scheme, developed on young male adults, is applicable to boys in late adolescence and has recently been extended into preadolescence In this classification the three principal components are named endomorphy mesomorphy and ectomorphy The relative proportion of each of these in several areas of the body is determined and an average figure for each is recorded The type number of the subject then will consist of three figures indicating these averages Ratings are on a seven point scale An extreme endomorph (excessive fat) would be given a 711, a mesomorph (predominately muscular) 171, and an ectomorph (slender) 117 Two studies relating physique to gross motor performance are of interest here

Jones (30) has compared small groups of boys from the California Adolescent Study who at maturity were rated predominately ectomorphic with a similar number rated mesomorphic The strength measures of the former were at all ages (12–17) below the average of the total group while those of the latter were consistently above average Correlations for 17-year-old boys showed that strength (grip, pull, thrust) was related as follows to

ectomorphy	− 25
endomorphy	04
mesomorphy	34
weight	52
height	33

When weight and height were partialled out, strength and mesomorphy correlated 61 Thus it may be seen that body form is an important factor in physical strength

[1] The McCloy and Cozens classification plans are very similar and correlate 9 or better with each other

In a study of muscular endurance, Cureton, *et al* (15) studied high school boys as well as college men The age range extended from 16–22 Of the 64 high school cases, 26½ percent were rated predominately mesomorphic, 23½ percent predominately ecto or endomorphic The best scores were made by the mesomorphs, the poorest by the endomorphs

STRENGTH

Muscular strength is closely related to body size and build but is more subject to environmental influence than the latter There is also a sex difference so that boys and girls of the same age, height, and weight are not alike in strength

Changes in grip strength with age have been studied by many investigators and large numbers of children have been tested Metheny (39) has summarized a number of these studies Although the instruments used and probably also the methods of procedure differ, the results agree that boys continue to improve until 18 years or older and that girls show a tapering off after the 14th year In 1950, Bookwalter (9) reexamined the studies made on males and presented curves for the years 9–24 The rate of growth is steady 9–14 accelerates 14–17, and shows a reduced rate of increase 17–24 The amount of change in boys 6–18 years was found by Meredith (37) to be 359 percent for girls by Metheny 260 percent

Jones (30) observed in the data of the California Adolescent Study that strength develops more rapidly than any other conspicuous aspect of physique Indeed, approximately four fifths of strength but only one third of height is acquired after the age of 6 Strength is so closely linked with individual growth patterns that it may in itself be regarded as an indicator of puberty and as a secondary sexual characteristic

Grip strength is substantially related to other dynamometric measures of [illegible]

puberty and strength Dimock (18) in 1935 studied 200 boys over a three-

year period He computed a Strength Index for groups of prepubescent, pubescent, and postpubescent boys, classified according to Crampton's criteria. At the same chronological age, pubescent boys were superior in strength to the prepubescent group and the postpubescent exceeded both of these others In fact, the postpubescent of 13 was found to be superior in strength to the prepubescent of 15. In the California Adolescent Study, both boys and girls were tested semiannually for strength of grip, "pull," and "thrust," by means of dynamometers When these data were grouped according to pubescent status, the finding of Dimock was confirmed for boys and similar results were obtained for girls Jones (30) used skeletal age as a basis for selection of early and late maturing groups of boys, and for girls, age of menarche as well All of the results show that the more mature boys and girls at the same chronological age are superior to the less mature in the strength measures studied In girls this superiority disappears in the fifteenth year, but is still evident in boys at 17

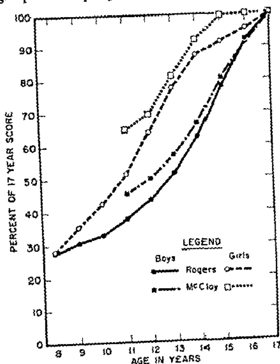


Fig 22 1 *Relative strength indices for boys and girls*

BALANCE

Balance plays a conspicuous role in postural locomotor development It may be thought of as a coordinated neuromuscular response to a variety of stimuli, tactile kinesthetic or visual in origin, primarily The response is regulated by the cerebellum and is performed for the most part without voluntary direction The vestibular organ (semicircular canals) plays an essential part in this mechanism if balance is of a dynamic rather than static nature Visual sensations supplement and in some cases of injury to the vestibul, may substitute for the latter

Because of the complexity of balance and also of the very wide range of ability change from early childhood to middle or later years, no single meas-

ures can be used over a wide age range In testing children, Bayley (5) included such static balance items as standing heel to toe, standing on toes, standing on one foot No items were attempted with eyes shut before the age of 5 At this time, standing toe to heel, eyes shut, correlated with the same test eyes open 53 (40 cases) Relationships among items were in general very low At no other age level were all of these same tests performed by a sufficient number of children to compute interrelationships At earlier ages, some of the items were too difficult, at later ones, too easy

The walking board has been used as a dynamic balance test over a wider age range than any other single test but the manner of scoring, size of board and general procedure has differed to such an extent that results are not comparable Progression in the early years is described best by Bayley (5), as follows

	Age in Months
Walking one foot on	27 6
Standing, both feet on	31
Attempting to step	32 8
Alternates part way	38
Alternates full length	56
Length* in 6 to 9 sec	59 5
Length in 3 to 5 sec	66
Length in less than 3 sec	80

* 2 5 meters long 6 cm wide 10 cm high

A railwalking test using rails or beams of graded widths, was given recently by Heath (27) to over 700 Philadelphia children ranging in age from 6–14 From 30 to 50 children of each sex at each age level were tested Boys improved more than girls but both sexes showed consistent growth In a similar study reported by Seashore (49), on boys 11–17 years, little change occurred over the entire age range Several more recent studies (16,22) have not agreed with the Seashore findings, however It seems probable that dynamic balance can be expected to show improvement with age, and as more refined measures are devised the course of change will be better understood There is some indication that rate of growth in balance in boys may be temporarily retarded at puberty In one study (22), pubescent boys were found to show little or no change whereas both pre and postpubescent groups improved steadily A great deal of research is needed in this area

COORDINATION

When an individual moves easily and the seq[illegible] timing of his acts [illegible] essential ele[illegible] To be sure high achievement in any event implies good coordination But some aspects of this quality can be measured more directly by the Brace test (10) of general motor ability This graded series of stunts measures the ability of

the individual to manage his own body in such events as jumping into the air and clapping the feet together once, balancing for five seconds on the hands with knees resting on elbows, sitting on the heel of one foot without touching the other foot or hands to the floor and then standing again The twenty tests in all which make up the Brace battery are scored on a pass or fail basis Although an attempt was made to select events to measure agility, control, balance, and flexibility, and to provide for even steps in difficulty, these aims have been imperfectly met Some individuals can pass all tests in this battery also, so that the range is not adequate for all abilities The test is fairly reliable and objective, however, and has been shown to measure abilities which are related slightly if at all to strength and height or weight This test battery has been used extensively and results have been reported for many age groups and for both sexes

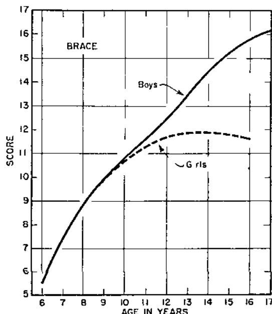


FIG 22 2 *Brace test*

When the test was first published, norms for children 8 to 18 were given and no sex differentiation was made Later studies have consistently reported marked sex differences in adolescence, however This difference becomes evident between 12 and 13 years of age and increases decidedly after 14 Girls scores on the average do not improve after 14 Boys scores show steady improvement over the entire range studied (Fig 22 2)

This growth pattern is not found in each of the twenty stunts of the battery, as has been shown in an extensive study of boys and girls covering the age range of 10 5 to 17 years (21) In several tests, girls are equal or superior to boys at a few age levels but in no case do they excel throughout The stunt which requires the subject to fold the arms across the chest, cross the feet and sit down crosslegged, then stand again without unfolding the arms or moving the feet about on the floor' shows least variation over the entire age range studied and least sex difference, also Boys are especially superior in agility measures which require rapid change of direction of the body or its parts Examples of this in the Brace battery are jumping full turns, with

position held at the finish, jumping through a loop made by grasping a foot in the opposite hand Older girls are less able to do these stunts than are younger girls But in stunts requiring control or static balance, older girls appear to hold their own," as it were

At puberty, boys show a reduction in rate of increase in Brace Test scores This is in contrast to development of strength But it should be noted that improvement still occurs Results of tests reported by Dimock (9) showed that prepubescent boys at 12, 13, and 14 years actually scored higher than pubescent and postpubescent boys at the same ages A later study by Espenschade (22) did not substantiate this, but did find a slowing of rate of change during pubescence Explanations of this temporary retardation of growth in motor coordination may be looked for in rapidly changing body proportions, unequal growth of limb length and muscles, inadequate synthesis of changing kinesthetic perceptions, or changes in the body image

The Brace test might be expected to measure qualities different from those found in running, jumping, and throwing, but investigators studying children 10–14 report correlations with these events of a magnitude similar to those between these activities themselves (19,35) In older boys, Espenschade found little relationship between the distance throw and the Brace test, but correlations for boys between the Brace test and running and jumping and all intercorrelations for girls were of similar order When the Brace test has been included in factor analysis studies it is found to have a low weighting in strength but a fair correlation with velocity Since these same factors are present in many gross motor performances, it is not surprising that this battery should be substantially related to running, jumping, and throwing

FUNDAMENTAL MOTOR SKILLS

Running, jumping, and throwing are common elements in active games Throughout the growing years boys and girls have opportunities for frequent participation in these and so develop these capacities Thus performance in running, jumping, and throwing may be used as an indication of motor ability, although it must be recognized that experience and training, interest and attitude play increasingly important parts in achievement Since these are the same basic activities that are important indicators of motor development in early and middle childhood, it is possible to study age changes and sex differences over a wide age range Two measures of jumping have been consistently used—the standing broad jump and the jump and reach Although techniques have differed slightly in some cases, the number of [illegible]

[illegible]

be computed from available records and so the data may be made roughly

comparable In throwing, the event commonly selected is a distance throw, but size and weight of ball and measurement of records differs somewhat from study to study In so far as possible, comparable scores have been obtained The results are presented in Table 22 1 and Figs 22 3, 22 4, 22 5,

TABLE 22 1 Age Changes in Motor Performance

Age	Run Yards per sec	Standing Broad Jump (inches)	Jump and Reach (inches)	Brace (score)	Distance Throw (feet)
		BOYS			
5	3 8	33 7	2 5		23 6
6	4 2	37 4	4 0	5 5	32 8
7	4 6	41 6	6 1	7 5	42 3
8	5 1	46 7	8 3	9 0	57 4
9		50 4	8 5	10 0	66 6
10	5 9	54 7	11 0	11 0	83 0
11	6 1	61 0	11 5	11 1	95 0
12	6 3	64 9	12 2	12 7	104 0
13	6 5	69 3	12 5	13 1	114 0
14	6 7	73 2	13 3	14 5	123 0
15	6 8	79 5	14 8	15 2	135 0
16	7 1	88 0	16 3	16 2	144 0
17	7 2	88 4	16 9	(15 9)	153 0
		GIRLS			
5	3 6	31 6	2 2		14 5
6	4 1	36 2	3 5	5 5	17 8
7	4 4	40 0	5 7	7 5	25 4
8	4 6	45 9	7 7	9 0	30 0
9		51 3	8 7	10 0	38 7
10	5 8		10 5	10 5	47 0
11	6 0	52 0	11 0	11 1	54 0
12	6 1		11 2	11 8	61 0
13	6 3	62 1	11 0	11 8	70 0
14	6 2	62 7	11 8	11 9	74 5
15	6 1	63 2	12 2	11 5	75 7
16	6 0	63 0	12 0	11 8	74 0
17	5 9				

SOURCE References 2, 3, 8, 12, 13 19, 21, 26, 29, 31, 32, 33 40, 42, 44, 45 50, 55
Scores presented are averages from available reports

22 6 Norms in many cases are given according to classification by age,

school Girls show improvement throughout the early school years but scores reach their maximum as early as 13 years of age in running and jumping and show little change after 13 in distance throwing Physical size and strength measures continue to increase well beyond this age level so this cessation of change cannot be due to attainment of physical maturity Some authors have attributed it to adolescent changes in build and development of secondary sexual characteristics However there is considerable evidence of loss of interest due to cultural influences An explanation in terms of capacity seems less tenable than one in terms of motivation

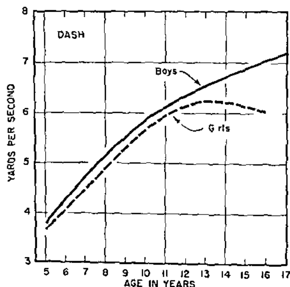


FIG 22 3 *Running*

Sex differences are present in all events at almost all age levels, but, due to the changing inflection of the curves for boys and for girls after 13 years, differences increase markedly after this time Times in the 40- or 50-yard dash are quite close for boys and girls aged 11 and 12 but boys are consistently superior In jumping and especially in throwing, the boys excel at every age level The magnitude of the difference in throwing is remarkable and is out of proportion to those in any other ph[illegible]
however,
tial practi[illegible]
other reasons have been advanced to date to throw light on these facts

The relation between pubescence and performance in these basic activi[illegible]

[illegible]

by the developmental extremes In jumping, throwing for distance, and basketball goal shooting, girls maturing very late excelled In the running events, and in rope-climbing, the early maturing girls excelled

In the California Adolescent Study (29) it was possible to group the girls

according to age deviation from menarche but there were very few cases studied as early as a year before this time When chronological age was held constant, correlations between physiological maturity and performance in most events was negligible

The picture for boys is different however, and resembles more closely the findings in relation to strength McCloy (33) investigated the influence of pubescence on performance and found it of some significance but discarded it as a factor in classification because of the difficulty in assessing stage of pubescence and the fact that its influence extends over a limited age range

More recently Nevers (41) has shown the relationship between a combined score in five track events (running, jumping, shot put) and the McCloy classification index, for each of three pubescent groups Pre and post pubescent boys improve steadily at each class but pubescent boys of all classes seem to score approximately the same number of points The rate of gain and the actual scores are greater for post pubescents at all overlapping indices These results differ from those obtained by the same author in strength measures, especially in regard to performance of the pubescent group

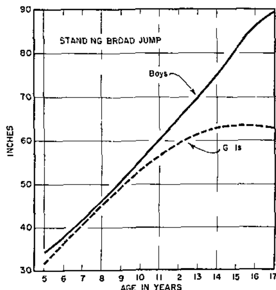


FIG 22 4 *Standing broad jump*

The determination of physiological maturity in the California Adolescent Study was on a different basis, and three phases or zones of pubescence were tentatively identified When the several motor tests were correlated with this estimate of physiological maturity (chronological age held constant) the highest relationship was found to be with the distance throw, the lowest with the broad jump Percentage change in performance according to zones of maturity was of especial interest as it appeared that boys in Zones II, III, and in early maturity each improved approximately equal amounts in the dash, whereas in both jumps, the largest proportion of change occurred in Zone II and in the distance throw in Zone III Thus the pubescent boy gains steadily in running, rather abruptly and early in jumping and somewhat later in throwing (19) This is in accord with the physical

growth sequence in which legs lengthen and hips widen earlier than shoulder girdle development occurs

Each of these basic activities differs from the others not only in developmental pattern but in qualities required for performance This is readily seen when test scores are intercorrelated It is true, of course, that errors of measurement must be considered in studying relationships found In running events, stop watch timing even when carefully done is subject to considerable error This is especially true in the case of records for young children when the distance run is only 35 or 40 yards The additional problems in testing children—of simple, clear directions which the child surely understands, of attention span, of interest and effort, may all contribute to error Experienced experimenters, however, have obtained reliabilities in running events of 88 (26) for 4-6-year olds, and coefficients of the order of 9 are frequently reported for older children

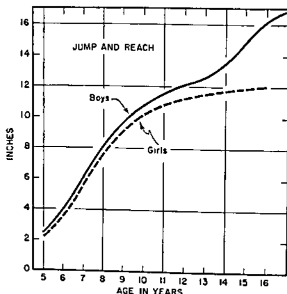


FIG 22 5 *Jump and reach*

Jumping can be measured still more accurately, especially the broad jump Reliability coefficients range from 82–89 for elementary school children to 95 or above for senior high school boys Throwing tends to be highly reliable when reasonable care in procedures is maintained Coefficients of the

Quite possibly motivation is a factor here Certainly reliability may be ex

tance, many studies on boys have selected this event McCloy (33) has shown that either a distance throw or a shot put may be used in combination with running and jumping to predict "total points" on a larger number of

track and field events for boys The majority of physical activity programs for girls do not include a shot put, however As the technique of performance must be learned, this event ordinarily cannot be used as a test for girls

Intercorrelations between the dash, broad jump, jump and reach, and indoor baseball (softball) throw for distance as reported by a number of investigators are given in Table 22 2 Certainly no consistent trends are evidenced There does seem to be a tendency for relationships between events for boys to be greater at the junior high school level than before or after this time In the case of the girls, however, correlations are of approximately the same order at all age levels Those between dash and broad jump are approximately 6 while those between dash and distance throw and between distance throw and broad jump average more nearly 4 More investigators have reported figures for boys and less consistency appears among these It would certainly be premature in the light of the available evidence to draw

TABLE 22 2 Intercorrelations Reported by Various Investigators

	Dash with Broad Jump			Dash with Distance Throw	
Age	Boys	Girls	Ref	Boys	Girls
49–78 mo	53		(26)	36	
1st 3 grades	475	576	(11)	244	442
10–14 yr		61	(35)		43
10–13 yr	665		(unpub)	502	
Jr HS	642		(46)	545	
	787		(47)		
	64	61	(19)	38	51
	67	64	(19)	48	44
Sr HS	44		(33)		
	76		(33)		
	58	60	(28)		
	48	45	(19)	38	41
	49		(19)	24	23
		57	(44)		
	Broad Jump and Distance Throw			Broad Jump with Jump and Reach	
Age	Boys	Girls	Ref	Boys	Girls
49–78 mo	41		(26)	53	
1st 3 grades	311	441	(11)	401	547
8 year	58	35	(49)	63	62
10–13 yr	53		(unpub)		
10–14 yr			(35)		49
Jr HS	721		(46)		
	39	45	(19)	42	30
	60	51	(19)	45	37
Sr HS	46	48	(19)	65	56
	47	42	(19)	51	64
			(1)	604	

conclusions in regard to the organization of motor abilities in children of 6-18 years

Nor are factor analysis studies adequate to throw real light on this subject Analyses of this type have been made for the most part on data from college men Selection of tests given and resulting emphasis in factors extracted has been different in the different studies Although strength or power and speed or velocity are identified in practically all cases, these two factors are not adequate to account for all components underlying performances in running jumping and throwing And the relative importance of even these factors is not firmly established

In tracing the course of development of postural locomotor control from infancy through adolescence, two basic concepts emerge Structure and function are found to be closely interrelated at all times, there are wide individual differences in rate of maturation, but the over all pattern of development is the same for all In infancy, developing neural structures especially seem to bring about rapid changes in motor behavior Sex differences in rate of maturation may be observed in childhood in the earlier age at which girls perform such activities as hopping and skipping in comparison to boys At puberty, a marked change in rate of development is again evident In boys, the postpubescent period is one of continuing development in motor performance, in girls little change appears after puberty It must be recognized that the marked sex differences at adolescence are due in part to experience and training, interests and attitudes as well as to capacity

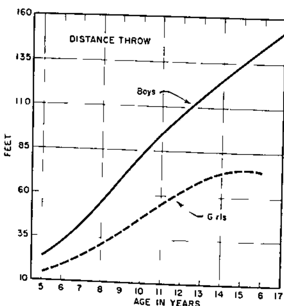


FIG 22 6 *Distance throw*

period of most rapid physical growth, at puberty In spite of these differing growth patterns, measures of coordination, of running, jumping, and throw

ing are substantially intercorrelated at all ages 4 17 It is possible that the cross sectional data including as they do a range of maturity levels may obscure the true picture here as is true for the curves of growth It may be that maturity itself operates as a factor to increase the size of the intercorrelations

Extensive data on the same children over this entire age span are needed to answer fully the questions raised in this review but a variety of investigations of smaller scope may make substantial contributions to this field

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23

G LAWRENCE RARICK

Exercise and Growth

SUMMARY

This chapter has been written with the purpose of presenting scientific information from several fields of knowledge concerning the effects of physical exercise on human growth Since little information is available on children who have been exposed to a lifetime of heavy physical activity, it has been necessary to draw upon the results of animal experimentation and upon the findings from limited observations on human beings Both genetic and environmental factors have been considered in some detail as a frame of reference for making inferences concerning the effects of exercise on the growth of children That the general morphological characteristics of the individual tend to persist throughout the growing years in spite of different environmental influences indicates the significant role of inherent factors in growth

Certain undefined minima of muscular activity are essential for supporting the normal growth and health of bone and muscle tissue, for experimental research has demonstrated that muscles which have lost their motor nerve supply atrophy within a period of a few weeks, as do the muscles of limbs which have been immobilized Likewise muscles with intact nerve supply

and tend to be lost after training is discontinued Evidence indicates that intensity rather than duration of activity is the important factor in promoting gains in muscular power and muscle size

In respect to the lasting effects of exercise on growing organisms controlled experimentation in which animals have been exercised throughout a lifetime has shown that only limited differences in general body size occur between the exercised animals and the unexercised controls Studies of

exercised animals show a lower percentage of body fat, a correspondingly greater weight of the musculature, and a positive effect on certain of the internal organs With discontinuation of exercise during the growing years, the gains achieved tend to be partially retained for the remainder of the growth cycle In general the data on animals indicate that some increase in mineralization of bone occurs as a result of exercise during the period of growth, but the increase seems to be in the direction of greater bone diameter with little effect upon bone length

The limited data available on exercise and human growth tend by and large to parallel the findings on animals The evidence suggests that a childhood devoted to heavy muscular activity tends to accentuate lateral growth, i e, increase in breadth and girth measures, with little noticeable effect on height On the other hand long bone growth in those segments which do not support the body weight appears to be positively influenced by extended periods of use Experience has shown that children who lead an active and vigorous childhood have firmer, stronger, and more supple muscles, with sturdier physiques and less adipose tissue than children who follow a more sedentary existence From the evidence now available it appears that exercise promotes the nitrogen retention and protein building powers of the body, thus contributing to the effective use of the nutrient supplied to the cells

The critical question as to the amount and intensity of activity which is needed for optimal growth cannot be answered conclusively at this time Present knowledge indicates that a given exercise program will not have the same effect on all children and may vary from one developmental period to another

Consideration should also be given to more than observable changes in physical dimensions for the most dramatic effects are those which are related to skill development, improvements in efficiency and economy of muscular movement, and gains in muscular power and physical endurance While certain morphological changes may occur as a result of physical exercise, some of which may persist into adult life, the more important consideration is the effect which physical activity may have upon the individual s physical powers and the effectiveness with which he uses his body

The drive for physical activity is strong in the young Free, unrestricted muscular movement is believed by psychologists to constitute one of the great hungers of life, a hunger in the young equal in intensity to that for food and rest (52) Physiologists recognize that human tissues and organs respond positively to healthy use and that with continued disuse these structures tend to atrophy As Carey (8) has pointed out, there is general agreement that parts of the body increase or decrease in size in proportion to functional demand or use However, the specific role which exercise plays in the growth phenomenon is not entirely clear Nor is there agreement as to the amount or intensity of exercise required for supporting optimal growth

and development Periodically, concern is expressed for the apparent inadequacies of physical education programs for children and youth Those who hold strongly to the view that exercise is a vital factor in stimulating growth, question whether children growing up in our present highly mechanized culture have sufficient physical activity to realize their growth potentials Others feel that the need for exercise is largely met by the natural play instincts of children, if these instincts are not thwarted by environmental circumstances There is a need therefore for scrutinizing closely our present knowledge concerning the effects of exercise upon human growth not only as a guide for current practices, but also as a means of pointing the way for future research

In an effort to bring together a broad range of research findings on this subject material has been drawn from the work of biologists, physiologists, anthropologists, physical educators, and child development specialists A brief overview is given of present concepts of growth and the role which certain intrinsic and extrinsic factors play in physical development as a means of providing the reader with background information for interpreting research on the effects of exercise on the growth phenomenon

THE NATURE OF GROWTH

Growth is a term which is broadly conceived It has come to have many meanings, such as increase in linear dimensions, gain in weight, protein synthesis, cell differentiation, cell migration, reproduction, and mitosis The

gradually attains the mature state These changes involve differentiation and

of the body or body segments, alterations in the tissue components, and changes in the internal organs Recognition is given to the fact that the various manifestations of physical growth are reflected in the expanding func-

cal problems in his attempt to make well controlled observations on a phenomenon so complex that its intricate nature still evades scientific in

quiry In fact, knowledge of the phenomenon has not yet reached the point where an acceptable theory of growth has been developed (72) Scientists have however, provided considerable factual material concerning the variables which influence growth For example, it is well established that genetic endowment plays a major role in all growth processes Likewise, there is agreement that the environment in which the organism grows and the internal physiochemical setting for cellular activity influence the final manifestations of growth However as Weiss (72) points out environmental forces are incapable of bringing into being new patterns of growth for which the organism was not already predisposed, although the inherent pattern of growth is subject to modification No nutrient or chemical or physical agent *is able to force a cell to perform any function other than that originally* planned by nature Hence no chemical or mechanical agent can be classed as a prime determiner of differential cell growth However certain conditions of the environment can materially impede the developmental processes whereas others may aid the organism to achieve optimum development Therefore any effect which exercise or any other growth factor may have upon development must remain within the framework of growth as determined by the native endowments of the organism

GROWTH PHENOMENA OF INTRINSIC ORIGIN

Growth is an orderly phenomenon and holds closely to the developmental pattern characteristic of the species Although individual variations may be found among life forms within species these differences do not overshadow the similarities of closely related life forms The same can be said for normal variations due to sex or to differential rates of maturation, for such differences, while important, do not alter the orderly and predictable nature of

or accentuated because of the operation of apparently unrelated intrinsic growth factors

The power of intrinsic growth factors in shaping the developmental pattern of the human is shown by the orderly and sequential nature of physical development in which the tempo of growth fluctuates from one developmental period to another, declining during infancy and early childhood, stabilizing in rate during middle childhood, accelerating again in early adolescence, and slowing down in later adolescence As Krogman (41) points out, the general theme of growth is integration in which there are periods of linear growth followed by periods in which the frame fills out These processes in terms of timing are a function of inherent growth factors and are only incidentally affected by the environment Just as the early years of life are characterized by a relative loss in adipose tissue, so the adolescent years

in the male are characterized by an accelerated growth in muscle tissue and marked gains in muscular power At one developmental period nature appears to be concentrating upon the growth of a particular tissue only to shift the focus to another at a later time

The significant role which intrinsic factors play in determining the course

factors which tend either to accelerate or retard growth may temporarily alter the course of development, but once the disturbing factors are removed the organism tends to return to the developmental schedule originally established by nature While there is considerable evidence to support the concept of developmental line the critical time necessary for either positive or negative growth factors to affect the final course of development has not been determined This would indicate that any attempt to study the influence of exercise upon final growth would necessitate application of the exercise variable over a long period of time

There is considerable evidence to indicate that inherent growth factors play a prominent role in establishing a morphological pattern of growth which remains relatively constant throughout the growth period For example, Garn (22) found that in spite of qualitative and quantitative differences in diet, genetically related children tended to maintain similarities in body build and body proportions Similar results were obtained by Dupertuis and Michael (14) in which growth curves of 26 ectomorphs and 28 mesomorphs who had attained an average age of 21 years were analyzed A

built mesomorphic boys seldom become ectomorphic adults and linear framed children do not normally develop into mesomorphic adults This

same rank order over a fairly long period of time

While similarity in body form tends to persist during the growing years the pattern of growth is in no sense rigid For example, Garn (20) showed that attempts to fit individual growth curves to rather arbitrary standards of growth were not entirely successful since most children deviated from the percentile standards with only a few children maintaining a "channelwise

in position over the period of the study, for the children with broadest hips at 5 years of age were not necessarily those ranking high in hip width at 9 While there was a high correlation between hip width measures at 5 and 9 years of age, 58 percent of the children had a change in percentile rank of up to 9 percent during this period Thus it would appear that while the general morphological pattern of the individual shows considerable stability during the growing years, nature does follow the principle of individuality of growth

Maturation as a Factor Affecting Growth

The process of becoming physically mature results in morphological and functional changes which are attributed primarily to inherent growth factors While the most dramatic physical changes occur as the child is approaching sexual maturity, rather subtle changes which clearly differentiate the early from the late maturing child occur at a much earlier age The rate at which the skeleton is ossifying reflects in some degree the speed with which the child is approaching sexual maturity With children who mature early the ossification centers of the hand, wrist and knee are markedly advanced at every age over those who mature late (25) The accelerated growth of the skeleton of early maturing children is also reflected in a greater mean height and weight for this group (59,61) Not only are the earlier maturers taller and heavier throughout middle childhood, but this group tends to be predominantly of mesomorphic physique while the late maturing, slower growing children are by and large of ectomorphic body build (14,6) According to Reynolds (56) the rate of maturation is also related to the growth of muscle, bone, and subcutaneous tissue In a longitudinal study of 48 girls and 30 boys in which repeated roentgenographic measurements of the calf were taken over the age range 7½ to 12½ years, Reynolds reports that for both sexes greater gains were made by the early maturers in muscle and bone tissue during this age range than was the case for the late maturing children

The effects which a variable such as exercise may have upon growth become difficult to appraise when consideration is given to the intrinsic growth factors which appear to be important in determining maturational rates, body build, and the quantitative and qualitative condition of the tissue components Does the constitutional make-up of the child predispose him toward extensive play and vigorous physical activity or are the physical manifestations of the young mesomorph a result of heavy physical activity? There is some indication that intrinsic factors play the dominant role, for the evidence now available indicates that individuals of mesomorphic frame respond to exercise with greater increases in muscle mass than do individuals

level of muscularity According to Lindegard both the minimal and maximal muscularity attainable appears to be relatively constant for the individual, which is indicative of the importance of genetic factors in the development of muscle tissues It is interesting to note that Jones (34) found that with adolescent boys 75 percent of the variance in strength was accounted for by 5 factors related to body build leaving only a small portion for factors associated with exercise Since no data were presented on the exercise programs of the subjects, this should not be interpreted to mean that exercise can be excluded as a variable which may have contributed in some way to differences in morphology

Sex and Growth of Somatic Tissue During Childhood

Boys and men tend to be more muscular and heavier boned than girls and women, whereas females possess a greater abundance of adipose tissue (54) This is particularly true as the secondary sex characteristics of adolescence appear However, it should be noted that early in life sex differences in the tissue components exist Stuart and co workers (64 65,66) using roentgeno-

[illegible]

tive amounts of muscle tissue available to boys and girls no information is

[illegible]

itative sex differences in the muscle tissue Indirect evidence on qualitative sex differences in active body tissue is given in a study by Garn (21) in which boys and girls were paired on the basis of measures of muscle size [illegible]

[illegible]

brought about by exercise regimens of the sexes is not known The latter would perhaps logically account for the difference because of the distinctive role assumed by each sex in our culture, since strength and power are believed to be male attributes and are more sought after by boys than girls even at the earlier ages

Endocrine Functions in Growth

The rapid morphological and physiological changes which are characteristic of the adolescent growth spurt are largely under the control of hormones While exact knowledge of the functional interrelationship existing among the endocrine glands is still not known, the specific growth effects of certain of the hormones are reasonably well established There seems to be little doubt that the accelerated growth of the body during this period is in a large measure due to the action of the pituitary growth hormone Among its numerous metabolic functions the growth hormone stimulates the processes whereby protein is built into muscle tissue and fat is expended to meet the increasing energy demands of the body During the adolescent spurt the protein building effects of the growth hormone are enhanced in the male by the male hormone According to Korenchevsky (38) skeletal muscle shows remarkable growth responses to testosterone resulting in increased weight of muscle tissue and enlarged muscle fibers On the other hand, female hormones in themselves have the long term effect of inhibiting growth and offer little in the way of stimulus for nitrogen retention This then indicates a rather fundamental sex difference in the role which hormones play in growth and offers some physiological basis for sex differences in the strength and power potential of the adolescent male and female

The secretions of the adrenal cortex also play a significant role in the growth phenomena at adolescence While cortisone favors protein catabo

duced in the female as well as the male, thus providing a proper biochemical setting for building protein in both sexes (23) However, the effects of the androgenic steroids are normally kept in check in the female so that the female does not develop the muscularity commonly seen in the male Only in cases of adrenal tumors in which there is intense production of androgens is there seen virilization in the female with the unusual muscular development of the male type

There is general agreement that the adrenal cortex as well as the gonads markedly increase their production of sex hormones at adolescence The fact that the secretion of testosterone as well as the androgens and oestrogens may vary substantially within a sex, accounts for marked variations in both general morphology and muscularity within a sex The rather definite feminine character of the physiques of some males and the masculine features of some females provides visual evidence that the general morphology of the sexes are not clearly dichotomized The role which somatic androgeny plays in affecting muscular development and strength is indicated by Bayley s work (5) in which somatotype ratings were made on adolescent boys and girls with particular reference to making judgments on masculinity feminin

ity tendencies in physique It is perhaps significant to point out that while
the average stre
than that of th
stronger per uni

The extent to which there is a close temporal relationship between increased endocrine activity and increased increments in strength and size of muscle tissue is not known Shock (58) has demonstrated a close parallel between the amount of creatine excreted by the kidneys and growth in strength The creatine concentration in the urine is known to increase during early adolescence reaching its highest concentration at about the time of maximum growth in stem length and at about the time strength increments are at the maximum Tanner (68) is of the opinion that at adolescence growth in muscle size comes first and is later followed by an increase in strength He believes that the strength increases at this time are due to the action of adrenocortical and testicular hormones on the protein structure and enzyme activities within the muscle fibers The belief that growth comes first and strength later is supported by the finding of Jones (34) who reports that with rapidly growing early maturing boys growth in strength tends to fall behind general body growth According to Tanner (68) about a year may pass before a boy just completing his physical growth will have the strength of the young adult of his size and build

It is interesting to note that the process of becoming adolescent frequently accentuates certain physical attributes of childhood For example, Garn (19) demonstrated that boys who were muscular prior to the adolescent growth spurt tended to become disproportionately muscular, while rotund, poorly developed boys showed little gain in muscularity during early adolescence How much these patterns of growth may have been influenced by diet and exercise is not known While these differences prior to adolescence are probably associated with the hormonal pattern of the child, the onset of ado-

adolescence

EXTRINSIC GROWTH FACTORS

Of the many extrinsic factors which normally affect physical development, nutrition is perhaps the most important The effect of improved nutrition in this country has significantly influenced physical growth trends This is borne out by reports during the past two generations, which have shown a gradual increase in stature of American children and youth For example, Meredith (46) noted that school boys of today are about 7 percent taller and 14 percent heavier than boys of equivalent ages 50 years ago Likewise, the average height of Toronto school boys 13 to 14 years of age was found to

be approximately 9 centimeters greater than the average stature obtained 50 years earlier (48) Conversely, the effects of a less desirable environmental setting are given in a report on German school children extending over a 40-year period including both World Wars I and II in which a marked falling off in both height and weight was noted during these periods (32) This was believed to be due to the marked reduction in calorie, protein, vitamin, and mineral content of the diet which accompanied the food rationing periods of 1914–1920 and 1935–1945 respectively

In the case of young animals fed on a diet relatively rich in the essential foodstuffs, but in quantity insufficient to maintain normal increases in

cles were of small diameter Children living under conditions of extreme deprivation follow similar growth patterns and tend to protect their limited energy resources by a marked reduction in physical activity Under conditions where good nutrition prevails, physical activity is believed to be important not only in creating a demand for food, but also in the effective utilization of food as is indicated by the firm solid tissues which are characteristic of the energetic healthy child The effects of exercise on growth can hardly be considered as a factor unrelated to nutrition for the sources of energy needed to support physical activity must come from food, and in turn the need for nourishment comes in part from the energy demands of exercise

Prolonged illness and chronic disease can have a profound effect upon the physical growth of children with accompanying loss of appetite and nutritional and metabolic disturbances However, illnesses of a more or less temporary nature are not believed to markedly disturb the long range pattern of growth For example, cumulative health records maintained over a period of approximately 14 years by Hardy (26) showed that frequency of illness had no discernible permanent effect on physical growth when comparisons were made of the yearly gains made by those cases having much illness with those having little The data suggest that while illnesses of limited duration may momentarily affect growth, the spurt in growth during convalescence tends to put the child back on a normal schedule of development

Habits of sleep and rest cannot be ignored as important factors in normal physical growth of children The undesirable effects of inadequate rest upon the general health and nutritional state of children is widely recognized Loss of appetite frequently occurs with children who have become chronically fatigued The anabolic processes are believed to occur primarily during periods of sleep and rest, hence it has been stated that much of the child's growing and lengthening occurs during sleep (9) Observation of the sleep patterns of children indicates that during periods of rapid growth the organ

ism seems to demand more time for sleep There is a natural tie between exercise and rest, for heavy exercise must be followed by the recuperative processes of rest, and in turn rest in the young is followed normally by the desire for physical activity

The seasonal effects on growth, although not great, are sufficient to have a measurable influence on growth curves The evidence now is rather conclusive that growth in height is fastest in the spring whereas the autumn months are most favorable for gains in weight (18,57) Jones (34) reports that seasonal variations occur in growth in strength during adolescence, the greatest gains being made in April, the smallest in October Although the biological factors involved in seasonal effects on growth are not known, some believe these variations are due to differences in glandular activity since nutritional factors do not appear to be involved (68)

EXERCISE AS A FACTOR AFFECTING GROWTH OF MUSCLE

Physiologists have repeatedly verified the commonplace observation that muscles increase in size as a result of regular periods of heavy physical exercise Gains in strength also accompany increases in muscle size although the strength increments are usually proportionately greater than the increases in muscle girth As Mor

fibers normally used (35) As muscular hypertrophy occurs there is also an increased vascularization of muscle tissue, more particularly an increase in the capillary bed of the exercised part Petren (51) believes that exercises of

intensity of exercise than to the duration This was demonstrated by Siebert (60), who forcibly exercised rats over a period of six months on motor driven drums In his experiment all rats ran the same distance, but the speed of running was systematically varied for different animals Siebert found that the greatest muscular hypertrophy occurred in the leg muscles of the animals which were forced to run at high speeds Only mild hypertrophy was produced at moderate speeds of long duration and only when the rate

over long periods of time accomplishes little in the way of building muscle tissue or developing strength

Accompanying the hypertrophy of exercise chemical changes occur in the muscle tissue which include substantial increases in muscle protein, muscle glycogen, phosphocreatine, and muscle hemoglobin (35) The question as to whether the stimulus for the hypertrophy of exercise is the mechanical involvement of tension and pressure or a chemical phenomenon is not as yet clear Hettinger and Muller (29) present the view that exercise triggers the growth mechanism in the muscle fiber only when an oxygen deficit occurs The data presented by these researchers indicate that strength increases most rapidly when the training load is increased from 1/3 to 2/3 maximum tension The hypothesis proposed is that only when the load is approximately 2/3 maximum are 'all the muscle fibers experiencing some oxygen want Early work by Muller had indicated that approximately 20 percent of maximal strength could be held almost indefinitely and that strength building effects were not noted until static contractions reached 1/3 the maximum level In stimulating muscle growth and building strength Hettinger and Muller believe that sustained isometric contractions are more effective than isotonic contractions and that for each muscle there is a range of exercise loads for building strength, the lower level being sufficient to throw only a few fibers into oxygen debt, while at the upper limit (approximately 2/3 maximal strength) all fibers are placed in oxygen debt

The possibility that chemical agents formed in the contracting muscle may activate growth should not be overlooked, for Steinhaus (62) cites evidence that the feeding of tetanized muscle tissue to tadpoles is effective in stimulating muscle growth The effects of testosterone and the androgens upon muscle growth have been previously mentioned Increased activity of certain of the endocrine glands during periods of training has been suggested as a possible stimulus for growth of muscle tissue Again the immediate stimulating factor is elusive As will be pointed out in the next section, a considerable body of evidence is aligned on the side of mechanical tension as the most significant factor in initiating the reactions resulting in the maintenance and growth of muscle tissue

Stress as a Growth Stimulant Athletic coaches and physical educators base training programs on the belief that when the human body is repeatedly placed under conditions of physical stress the organs and tissues involved tend to react by overcompensating both structurally and functionally in such a way that gradual improvement in performance results The validity of this concept has been established not only in respect to the muscular hypertrophy associated with heavy physical activity but also in the compensatory responses of the body to biological stresses of many kinds As one example, in embryological development stress is recognized as a major morphogenetic factor particularly for tissues of mesenchymal origin In the

structural development of cartilage, bone, blood vessels, fascia, and muscles the orientation of the cells and the intercellular fiber systems is dependent upon the mechanical tensions involved, such orientation occurring in the direction of the applied stress Weiss (72) states that many of the tensions occurring during normal development are from intrinsic sources and are the result of the interplay of local shifts in intensities of growth involving stresses brought on by expanding or contracting areas This does not preclude the influence of extrinsic tensions in orienting the form and direction of growth In fact, it is recognized that any physical force which affects the orientation of the molecular matrix of the cells may alter structural design

While it is recognized that physical stress is important in shaping the structural arrangement of tissues, it must be realized that tension is not the determining factor in cell differentiation It may, however, be a significant factor in enabling the cells to achieve terminal transformations for which they were originally predisposed For as Weiss points out myoblasts will not develop into muscle cells in the absence of stretch However, stretch cannot transform a non myoblast into a muscle fiber Stresses then of either intrinsic or extrinsic origin appear to be capable of not only altering the orientation of structure during early development, but appear to be important in helping cells, particularly those of mesenchymal origin, realize their destiny in the growth of normal body structures

Hellebrandt and Houtz (28) point out the importance of overload stress in increasing the capacity of the human body to perform severe exercise They believe that the increased capacity for work brought about by overload stress is in a large measure due to changes in the central nervous system and not, at least initially, to changes in basic structure The fact that performance changes seem to occur more rapidly than modifications in structure gives support to this point of view

Denervation Atrophy and Atrophy of Disuse Additional insight into the matrix of factors which affects the growth and maintenance of muscle tissue has been gained from observations which have been made on denervation atrophy and atrophy of disuse (16) In cases where the nerve supply to the muscle is lost there is a gradual wasting away of the active muscle tissue As Fischer (15) points out, the loss is characterized by a decline in muscle wet weight and muscle phase volume, a reduction in myogen, actin, and myosin and an increase in fibrous tissue and myoalbumin It should be noted that Kosman and others (39) found that in the case of denervated muscle, loss in tension occurred more rapidly and to a greater extent than weight loss The fact that these workers noted that tension returned more rapidly on reinnervation than the increase in weight, suggests that the gains in the protoplasm fixing power of the muscle are in some way enhanced as the muscle regains [illegible]

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Hines (31) demonstrated, daily weak galvanic stimulation had only a mild effect in retarding the weight loss of denervation atrophy, whereas prolonged and strong daily galvanic or faradic stimulation not only markedly retarded muscular weight loss, but also accelerated the return of muscle to its original size after re-innervation. There is general agreement that electrical treatment can slow down the weight loss in denervated muscle. Present research has also demonstrated that the use of electrical treatment with denervated muscles has the effect of maintaining larger and stronger muscle fibers at the time of initial re-innervation than would have occurred without the treatment. Those who hold to the theory that the tension effects are important in stimulating growth of muscle can point to the evidence of Fischer and Ramsey (17) in which stimulation of a loaded extremity proved to be more effective than stimulation of an unloaded muscle in preventing loss of muscle protein in denervation atrophy.

The rate at which the muscle atropies with denervation is relatively rapid, for the muscle loses approximately 40 percent of its dry weight in 2 weeks, 50 percent in 4 weeks, and 60 percent in 12 weeks. The rapid loss in muscle tissue brought on by denervation is believed by some to be due to the energy used in the endless, haphazard contractions of muscular fibrillation which begins 7 to 10 days after denervation and continues as long as contractile tissue remains. However, Abramson (1) cites evidence that electrical stimulation retards the rate of atrophy without reducing the fibrillation. This would suggest that the atrophy is not entirely a function of the muscular fibrillation which is brought on by denervation.

In atrophy of disuse resulting from immobilization of a part the rate of atrophy approaches that of denervation (30). When the muscle is made completely quiet by cutting all dorsal roots and transection of the cord, the rate of atrophy is the same as that under conditions of denervation (69). Likewise, in tenotomy atrophy sets in at the same rate as in the case of denervation but with no accompanying fibrillation. Application of passive tension to the muscle does not in itself prevent atrophy in cases of denervation, nor is atrophy prevented by activation of the muscle under conditions in which the normal tension producing function of the muscle is lost by severing the tendon of insertion. Therefore the active tension produced by the muscular contraction itself would appear to be the factor which prevents atrophy, for the greater the interference with this function, the more extensive the atrophy. This parallels what is known about the hypertrophy resulting from heavy exercise, the more tension the muscle is called upon to develop, the greater the hypertrophy.

EXERCISE AND BONE GROWTH

Steinhaus (62) in an early review of research on the chronic effects of exercise found little agreement among research workers concerning the

long term effect of exercise on long bone growth In citing evidence drawn chiefly from studies conducted in Europe, Steinhaus reported that a substantial body of these data supported the belief that the pressure effects of exercise on the epiphyses of bones had a stimulating effect on growth up to an optimal length, but excessive and prolonged pressure retarded growth Evidence of the effects of inactivation was presented from studies in which one limb in dogs was inactivated by a stiff bandage, resulting in bones lighter in weight and with less mineral matter than in the bones of the active limbs However, the bones in the immobilized limb tended to be longer and slenderer with histological evidence of more growth at the epiphyseal line The accelerated activity of the epiphyseal line was believed to be due to the lack of growth slowing pressure on the ends of the bones, whereas the slender character of the bones was attributed to the absence of the growth stimulating effect of muscular tension on lateral bone growth

Evidence obtained from humans who have become bedfast gives some insight into the role which physical activity plays in maintaining the normal structure of bone tissue Asher (4), in pointing out the dangers of prolonged bed rest, states that bones which are not subjected to normal use lose calcium

weeks There is also an associated nitrogen loss during this period which shows that complete physical inactivity results in a depletion of the normal stores of both calcium and protein Upon restoration of a program of activity there occurs a positive calcium and nitrogen balance

In motor paralysis the density of bone declines Regardless of the cause, muscular atrophy in children brings about a decrease in both bone diameter

but later the effects of disuse retarded linear growth by as much as 20 to 25 percent This led Howell to conclude that length of bone and the basic features in bony configuration are determined by inherent factors, whereas

by Tower (69) under conditions in which the normal nerve supply to the bone was retained but the part under observation was kept inactive The re-

sults eliminated neurotrophic action as a growth stimulant in the absence of nervously initiated activity in muscle The author concluded that function such as the weight bearing effect on the lower extremities was the primary factor in the maintenance of bone density Apparently the tension produced by muscle on bones and the pressure effects of supporting the body weight are of primary importance in maintaining the integrity of bone tissue

GROWTH STIMULATING EFFECTS OF PROTRACTED EXERCISE REGIMENS

The previous sections have indicated that certain undefined minima of muscular exercise are necessary for maintaining normal muscle and bone tissue and that muscular hypertrophy can be attained in a matter of a few weeks by intensive muscular training The importance of recognizing the role which nature plays in shaping developmental design has been emphasized as has the modifying influence of certain environmental factors Attention will now be given to examining information on the growth effects of extended periods of physical exercise Obviously controlled experimentation on human subjects in which the exercise variable can be carefully manipulated over a period of 12 to 15 years is impracticable Hence one must turn to experimental work performed on animals where effective controls

time of heavy exercise on the physical growth of animals are limited in number The work of Donaldson and Meeser (12), who observed the effects of exercise on two families of albino rats followed through seven generations, is noteworthy These investigators using litter mates as control and experimental animals observed the effects of daily exercise begun on the 56th day of life and continued for the next 170 days (human age equivalent, 4 5 years to 19 years) Each experimental animal ran approximately 5 miles per day in a revolving cage, the distance varying from 2 4 miles to 12 6 miles depending on the age of the animal Each paired control was kept in a stationary cage during the 170 days of the experiment At the conclusion of the experimental period all experimental and control animals were killed and the various tissues and organs were weighed The findings of the study showed that exercise in the male did not stimulate growth in either length or weight during this period However, in the female exercise resulted in rats slightly larger than the controls As a result of exercise most of the internal organs in both

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going loss in weight, this was assumed to be fat Furthermore, the experimenters concluded that apparently a sex difference in response to exercise

did exist, in that the female was more resistant than the male in respect to depletion of body fat. The view was expressed that the rats exposed to ample exercise were living under circumstances favorable for supporting healthful circulatory and metabolic conditions and that the response to exercise was most likely an expression of the capacity of the formed cells to respond. In the view of the writers the capacity for change was limited and therefore the response to a stimulus such as exercise depended on the extent to which the cells of the responding organs had reached the size limits imposed by nature. It is interesting to note that there was a moderate increase in the weight of the musculature which was in part masked by the loss of fat. Increases were large in the weight of the heart, kidneys, suprarenals, and gonads, whereas the thyroid and liver were smaller than in the controls. In making inferences to humans, the authors pointed out that several studies have indicated that in many ways the internal chemistry of man and the rat are similar and that there is reason to believe that man and rat are in like developmental phases at relatively equivalent ages. The authors could find no evidence of cumulative effects of exercise from generation to generation.

Hatai (27), in an earlier study on albino rats in which the animals were exercised from the third through the sixth month of life (human equivalent, 7 to 14 years), observed that the exercised animals showed slightly greater gains in weight than the unexercised controls but no difference in length. Substantially greater gains were shown by the exercised animals in heart and kidney weight with slightly greater gains in brain weight. The animals which were exercised for only 30 days showed proportionally smaller gains.

One of the questions which is frequently raised concerning exercise and growth is the effect upon growth of the time in the growth cycle when exercise is introduced. Donaldson (10) studied this problem with albino rats starting the exercise program with a small group of experimental animals when they were 25 days old (human equivalent of 2.1 years) and running them 0.6 mile per day in drum cages for a period of 31 days. A second group began exercise at 200 days (human equivalent of 16.6 years), running 1.2 miles per day for a period of 90 days. When compared to the controls the rats beginning the exercise at 200 days showed increases in tissues and organs similar to those given exercise early in life. The percentage deviations were approximately three times as great for the older rats and since the period of training for this group was about three times as long as for the younger animals, the author concluded that the response to exercise was of the same order regardless of age. The deviations were proportional to the duration of the training period and not a function of either age or the normal processes of growth at a particular age level.

an extended program of exercise This procedure was followed by Donaldson and Messer (13) in which 6 male and 6 female albino rats were exercised from the 57th to the 147th day of life while an equivalent number of litter mates previously exercised were kept as controls in stationary cages At the termination of this period both the exercised animals and the controls were killed and examined Another series of animals was exercised similarly, but at the end of the 90-day period of activity the rats were moved to stationary cages for 100 days of inactivity A third group was given 150 days of inactivity following the 90-day period of exercise In each instance tissue analyses were made of experimental animals and controls at the conclusion of the period of inactivity This method was used to ascertain the extent to which varied periods of rest would alter any gains brought about by exercise In general the results showed that for all organs and tissues examined, growth was accelerated during the 90-day period of exercise, but with the subsequent rest period the organ weights of the exercised animals tended to regress toward the weights of the controls However, following the periods of inactivity the organ weights of the exercised animals were still somewhat the greater The extent to which the organ weights of the exercised animals returned to normal' appeared to be a function of the length of the period of inactivity, being greatest following the 150 days of rest The tendency of the organs and tissues to return to the size of the unexercised controls was not due, according to the investigators, to shrinkage by abstraction of fluid, but rather to retardation of growth during the interval of inactivity These data would suggest that protracted exercise programs have a favorable effect on the growth of rats which is still apparent after long periods of inactivity

In summarizing his studies on the effects of exercise on the growth of the albino rat, Donaldson (11) concluded that body weight and body length tended to improve slightly under extended periods of moderate or vigorous exercise, the effects being more noticeable in the female than in the male The general trend for accelerated growth was attributed to improved nutritional status with an accumulation of muscle tissue and loss of fat With moderate exercise the gains in weight were marked, however, with excessive exercise there tended to be a loss in total weight

Most authorities who have experimented on the rat agree that prolonged vigorous exercise results in increase in organ weight, musculature, and bone weight with a drop in body fat The impetus given to growth by exercise applied during a portion of the period of growth tends to persist even after protracted periods of rest The characteristically greater gains achieved by the exercised female as compared to the male is attributed by Donaldson to the role which exercise plays in releasing the organs of the female from the inhibiting forces which normally restrain growth Donaldson's findings that exercise tends to increase the size of leg bones in rats is supported by data

presented by Steinhaus (63) in which daily exercise of dogs amounting to 6 miles per day resulted in approximately 5 percent increase in leg bone length

The importance of exercise in influencing the qualitative aspects of soft tissues should not be underestimated For example, Mayer (45) found that the difference in the fat content of the tissues of obese and nonobese animals was not so much a difference in caloric comsumption as in energy output Nonfasted nonobese animals were found by Mayer to be 50 to 100 times more active than obese animals, thus providing some evidence of the importance of activity in influencing the deposition of fat in animals The fact that inactivity usually preceded the development of obesity led Mayer to conclude that inactivity must be considered as a predisposing factor in the etiology of obesity As has been pointed out earlier one of the major differences in the growth of exercised and unexercised animals is the relatively smaller amount of body fat in the exercised animals and the proportionately greater amounts of active muscle tissue

Observations on Humans Most studies concerned with the growth effects of exercise on bodily dimensions of humans have been conducted over a limited period of time and the majority have dealt with subjects at or near their adult body size Only a few studies are available in which the exercise variable is clearly enough defined and extensive enough in duration to permit even tentative conclusions to be drawn One of the few attempts to examine the growth effects of heavy physical activity during childhood is the investigation reported by Adams (3) in which 100 Negro women, 17 to 21 years of age who had undergone a lifetime of hard manual labor were compared on the basis of several anthropometric measures with 100 young women of similar age who had engaged in no heavy manual labor The findings showed that the women who had engaged in heavy labor from early childhood were taller and heavier at the conclusion of the growing years

plantations and since the group came from a lower socioeconomic group than the nonworking Negroes, the authors concluded that the differential

or examining the more lasting effects of exercise The view has been expressed that the dominant hand and ... larger than the

ranges 1 to 4 years and 5 to 8 years found that children in the older age range tended more frequently to have longer right arms, forearms, forearms and hands, and wider palms than did children in the 1 to 4 year age range With college age adults the author found that the discrepancies between right and left sides were in the same direction as for the children, but greater in magnitude The findings indicate that the increasing use of the right arm with advancing age carries with it structural advances favoring the right upper extremity This argument is strengthened by the recent findings of Buskirk, *et al* (7), in which it was demonstrated that anthropometric and roentgenographic measurement of the hands and forearms of seven nationally ranked tennis players showed significantly greater osseous and muscular development in the dominant than in the nondominant member The investigators also obtained measures on a small sample of non tennis playing soldiers and while differences in size were noted favoring the right over the left hand and arm in these subjects the differences were much less than the laterality differences for the tennis players Since all of the tennis players had participated in this activity extensively in their teens, the authors expressed the view that exercise must have brought about some alteration in the osse

tremities with the added burden of weight bearing would result in both

the amount of muscular force they can develop Martin (44) and Kintis (36) noted that with boys in the age range 5 through 11 years gains in body strength occurred at a faster rate than increases in weight Asmussen and Heebøll Nielson (2) in checking actual gains in strength of boys in the age range 7 to 17 years against theoretical values based upon computed indices of body mass and muscle cross section, found that the observed gains in strength substantially exceeded the theoretical values based upon indices of size According to these writers the additional strength over and above that which might be expected to result from normal growth is explained either as a result of qualitative changes in the muscle tissue, or by more effective neural mechanisms which provide an increased ability to mobilize muscular power voluntarily With advancing age the child is perhaps able to call on more motor units simultaneously in an all-out effort Most certainly the effects of exercise upon muscle tissue during the growing years cannot be interpreted solely in terms of changes in muscle girths for the increases in functional power surpass the increases in size Of even greater significance is the improvement in efficiency and economy of muscular movement which according to Steinhaus (62) is the most prominent effect of training

It is evident from the data now available on the effects of exercise on

growth that one must be cautious in drawing conclusions If growth is used in its broadest sense, there is little doubt that development of neuromuscular skill improved efficiency of muscular movement, and increased capacity of the organism to perform work are all the direct result of systematic practice and training However, in respect to the morphological changes brought about by exercise the picture is not so clear There seems to be little question that certain minima of muscular activity are essential for supporting normal growth and for maintaining the protoplasmic integrity of the tissues What these minima mean in terms of intensity and duration of activity has not been ascertained Most certainly, the drive for physical activity in the healthy young child is so strong that these 'minima represent only a ... The gap between

ably changed muscle tissue increases as fatty tissue declines Likewise heavy ... of

mals the internal organs such as the heart, kidneys, and suprarenals, which are called upon to act vigorously in stress situations, show positive growth responses to exercise

Studies on animals indicate that the time of introduction of the exercise program into the life cycle of the animal is of less consequence than the duration or intensity of the program One might hypothesize that with humans more should be gained by introducing the program at the time when

somatic tissue

The way in which exercise triggers the growth mechanisms is not known There seems to be little doubt that stress in the form of mechanical tension

of body cells and in increasing the work capacity of the body, intensity rather than duration of activity being the critical factor

In appraising our knowledge of the growth stimulating effects of exercise, one must keep in mind that the capacity for growth is not the same for all individuals This is borne out by the limited data now available which indicates that extended periods of exercise bring about more pronounced

changes in the pattern of growth for individuals of mesomorphic build than for linear framed children However, general observation gives some support to the view that exercise by increasing the desire for food benefits nutrition and plays a supporting role in adding solid tissue to the slender small boned child Likewise, the impetus which nature gives to somatic tissue development at adolescence provides the medium through which exercise may rather extensively accentuate the muscle building powers of the male at this time

It should be kept in mind that the effects of exercise on growth cannot be entirely isolated from other growth variables, for the demands of exercise require rather extensive circulatory and metabolic adjustments which affect the entire body While conclusive evidence of the beneficial effects of vigorous exercise upon the growth of all organ systems of the body has not been established, continued use normally produces improved physiological responses in body cells The possibility that an inactive childhood may be the forerunner of undesirable developmental trends has not been adequately explored There is, however, some evidence to indicate that obesity may have its roots in childhood and that much of the problem of the slow and insidious accumulation of weight can be traced to physical inactivity (67)

Much remains to be learned concerning the effects of exercise on human growth At the present time recommendations concerning exercise programs for children are based primarily on experience rather than scientifically derived facts All too little information is available on the amount of exercise which children of varying maturity levels and different physiques need in order to achieve optimum growth The effects of exercise on physical growth can best be ascertained by making repeated observations on the same children over a long period of time under conditions in which the exercise variable can be applied under well-controlled conditions Even under the best of circumstances the problem of controlling nutritional factors and matters of daily routine makes such an undertaking difficult While only limited generalizations can now be drawn from animal experimentation and from fragmentary data on humans, scientific information is gradually being accumulated which will serve as a guide for developing more adequate programs of physical education for children and youth

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24

ARTHUR H. NORRIS AND
NATHAN W. SHOCK

Exercise in the Adult Years—with Special Reference to the Advanced Years[1]

SUMMARY

Studies of age differences in the physiology of exercise indicate that muscle strength and ability to maintain coordinated muscle work decrease with increase in age from a maximum in young adults 30 years old The maximum rate of oxygen uptake and maximum lung ventilation during exercise also show a marked decline with increase in age During submaximal work however, there is an increase in lung ventilation with increase in age Maximum heart rate decreases by about 40 beats per minute from age 20 to age 75 Mechanical efficiency of muscular work has been shown to decrease more in old subjects than in young subjects when work rate is decreased Slowing of physiological recovery from exercise and failure of coordination of the basic physiological processes may be partly responsible for reduced performance of older people The validity of physical fitness tests for older people is discussed

INTRODUCTION

single organ system or to failure of integration of the responses of several organ systems

[1] The authors wish to thank Dr Franklin M Henry, Dr David B Dill and Dr Sid Robinson for their helpful reviews of this manuscript

Studies of aging and the aged generate their own special problems. For example, the differences between individuals or groups of individuals of different ages are not necessarily the same as the changes that occur within individuals or groups as they grow older. The former comparison, sometimes referred to as cross sectional, can be made without waiting a finite time for alteration of the parameter or function being measured. The latter comparison, longitudinal in nature, demands continuity of the sample. Neither of these approaches is free of sampling difficulties. In the cross sectional approach, the question of the comparability of the subjects in the various age groups often arises. This is a difficult question to resolve for the determination of the genetic constitution or even the medical history of a large group of humans is a nearly impossible task. Moreover, arguments that genetic or environmental effects cancel out in the longitudinal approach are not valid unless (1) genetic factors are identified at birth and are assumed to be free of alteration (mutation) with the passage of time and (2) environmental factors are controlled or minutely recorded during the test period. The practical alternative to such idealistic barriers to progress is to accept the variance of such genetic and environmental effects as are difficult to eliminate, and to proceed with the identification of those age differences which emerge in spite of the high variance. Since this approach is far from unimpeachable, reasonable precautions are taken. Because of the increased incidence of recognizable disease in older people, the pertinent effects of such disease must be evaluated in the population under study. Medical selection and description are employed for subjects of physiological tests, for example, to eliminate or account for the gross deficiencies in the organ system or systems under test.

The present paper will have a primarily physiological orientation. We will attempt to present a review of the physiological literature as it pertains to old people. Where quantitative data are not available, we will indicate the need therefor. The application of physical fitness tests to older people will be reviewed and the relation of these tests to pertinent physiological literature will be discussed.

THE PHYSIOLOGY OF EXERCISE IN THE AGED

Strength and Maximum Work Output

Numerous reports of dynamometric measurements of muscle strength indicate that there is a marked reduction in strength with increase in age. As early as 1835 Quetelet (44) made this type of observation for young and old subjects. In subsequent studies Galton (47), Reijs (45), and Ufland (58) have collected strength data on 7000, 3000 and 4000 subjects respectively. These data indicate that there was better maintenance of strength in older people than was found by Quetelet. Simonson (52) has inferred a

relationship between this improvement in strength maintenance of older people and the increase in life span from Quetelet's time (1835) to the time of Reijs' study (1921) Fisher and Birren (19) have discussed the limitations of sampling of some of these studies

Miles (34) has used the simultaneous grip test in which the subject grips

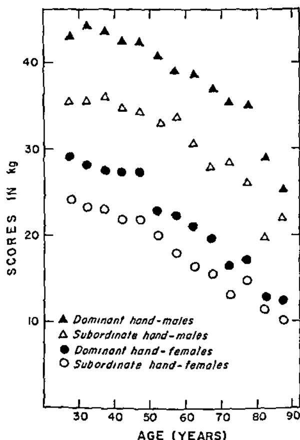


FIG 24 1 *Scores (kg) of the simultaneous grip test of Miles (34) are plotted against age (year) for 604 men and 553 women from 25 to 89 years old Scores of dominant hands for males* ▲, *and females,* •, *are separated from scores of subordinate hands of males,* △, *and females,* ○

two hand dynamometers at once His results for 604 men and 553 women[2] are shown in Fig 24 1 Burke, *et al* (9) have shown (Fig 24 2) that grip strength endurance, as well as grip strength decreases with increase in age in 147 subjects from 20 to 79 years old Grip strength endurance was defined

[2] Subjects were from a closed sample selected so that for each age semi decade the proportion of subjects with grade school, high school college, and superior college education was about equal

as the average strength that could be maintained for one minute Although the number of subjects in the higher age groups of both studies was small it seems clear that between 60 and 89 years both grip strength and grip strength endurance are reduced at a greater rate than between 30 and 59 years

Several authors have reported measurements of sustained coordinated

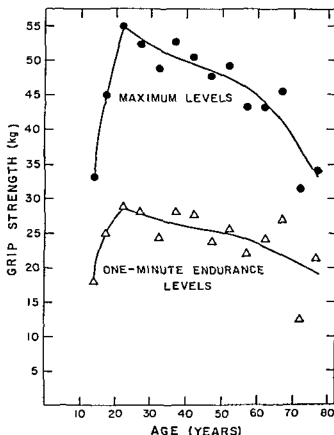
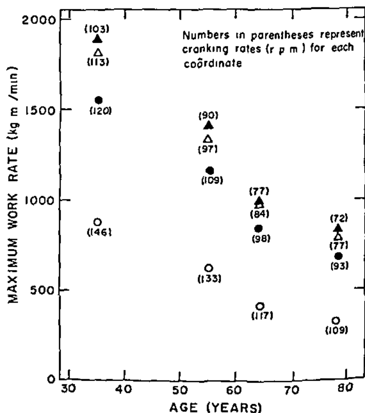


FIG 24 2 *Mean values of grip strength • and grip strength endurance Δ (kg) from the data of Burke et al (9) are plotted against age (year) Smoothed curves calculated from the data by the authors are superimposed*

muscular activity in older subjects Robinson (46) reports that 3 men from 73 to 76 years of age were able to walk for 5 minutes at 5 6 kilometers per hour on a motor driven treadmill set at an angle of 8 6 percent If we calculate work done in climbing the grade and neglect the work done in moving the body up and down in walking this corresponds to a rate of work of about 540 kg m /min Robinson s young subjects ran at a speed which ex

hausted them in two to five minutes Calculations of work rate from conditions of exercise administered by Sartorelli and Scotti (49) to their 10 subjects between 70 and 78 years of age indicate that these subjects may have walked at work rates as high as 475 kg m /min until metabolic equilibrium was reached Some of our subjects[3] performed a cranking exercise with their



(r p m) for each coordinate

of ... short

fol.

patients with severe cardiopulmonary and neuromuscular disease

bursts of exercise (5 to 10 seconds) was decreased with increased cranking rate The highest work rates for the older subjects were attained at cranking rates of around 70 r p m and decreased to work rates of about 350 kg m / min at cranking rates of 110 r p m The work rate that was maintained without decrement for one minute was 40 percent of these maxima, both in old and young subjects Thus our subjects over 70 years of age maintained an average manual work rate of 325 kg m /min for one minute as compared to 760 kg m /min for the young subjects Following this plateau there was a slow decrement in work rate until the work was discontinued

The only longitudinal data of this sort have been reported by Dawson (12) for bicycle ergometer rides by himself at 41, 53, 57, 68, and 71 years of age The subject trained for the exercise bouts by running, walking, mountain-climbing, and practicing on his bicycle ergometer The average work rate shown in Fig 24 4 for 30-minute rides decreased from 1380 kg m / min at 41 years of age to 953 kg m /min at 71 years of age The low values at 53 and 68 years of age are explained by the authors as due to technical difficulties such as improper adjustment of the bicycle ergometer seat Nonetheless, the relative performance based on the work rate at 41 years of age dropped to 52 percent by 71 years

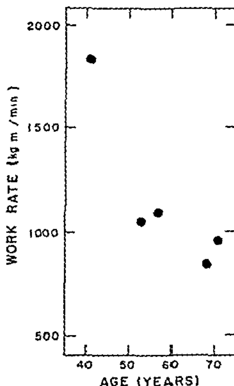
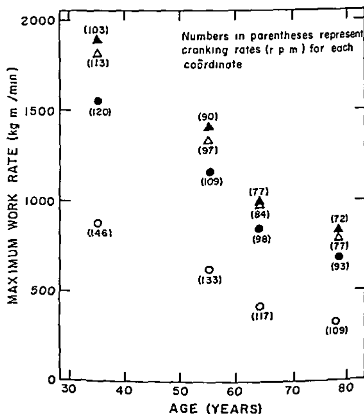


Fig 24 4 *Work rate (kg m /min) is plotted against age (year) for a subject who performed repeated measurements on himself* (12)

Androgen (methyl testosterone) has been shown to effect strength and work output in older subjects Simonson, Kearns, and Enzer (53) have reported improvement of weight lifting (8 lbs, 1 meter, 20 times/min), weight support time (8 lbs) and back muscle strength resulting from administration of methyl testosterone (40 mg /day) to 6 subjects from 48 to 67 years of age Before treatment, the subjects complained of excessive fatigability but had no detectable pathology Two of the subjects were maintained at levels of improved performance for 2 months and 8 months on 20 mg /day and 30 mg /day of methyl testosterone respectively Although

hausted them in two to five minutes Calculations of work rate from conditions of exercise administered by Sartorelli and Scotti (49) to their 10 subjects between 70 and 78 years of age indicate that these subjects may have walked at work rates as high as 475 kg m /min. until metabolic equilibrium was reached Some of our subjects[3] performed a cranking exercise with their



(r p m) for each coordinate

arms while recumbent on a bed. The electrical output of the manually operated ergometer which we used was proportional to the work done on the ergometer and was recorded throughout the exercise period Fig ... shows

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bursts of exercise (5 to 10 seconds) was decreased with increased cranking rate The highest work rates for the older subjects were attained at cranking rates of around 70 r p m and decreased to work rates of about 350 kg m / min at cranking rates of 110 r p m The work rate that was maintained with out decrement for one minute was 40 percent of these maxima, both in old and young subjects Thus our subjects over 70 years of age maintained an average manual work rate of 325 kg m /min for one minute as compared to 760 kg m /min for the young subjects Following this plateau there was a slow decrement in work rate until the work was discontinued

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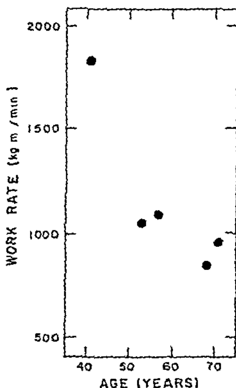


Fig 24.4 *Work rate (kg m /min) is plotted against age (year) for a subject who performed repeated measurements on himself (12)*

Androgen (methyl testosterone) has been shown to effect strength and work output in older subjects Simonson, Kearns, and Enzer (53) have reported improvement of weight lifting (8 lbs, 1 meter, 20 times/min), weight support time (8 lbs) and back muscle strength resulting from administration of methyl testosterone (40 mg /day) to 6 subjects from 48 to 67 years of age Before treatment, the subjects complained of excessive fatigability but had no detectable pathology Two of the subjects were maintained at levels of improved performance for 2 months and 8 months on 20 mg /day and 30 mg /day of methyl testosterone respectively Although

these positive effects of androgen therapy are encouraging in these subjects who complained of fatigability, the authors point out that the identification of the basic effect should be made in subjects who do not have such complaints Since androgens induce a wide variety of metabolic and physiological effects, their administration to older people can be recommended only on an individual basis on the advice and under the control of a physician

Lack of motivation of the subject might cause low estimates of performance Although this possible source of error is always present, most workers agree that most subjects are adequately motivated and that this judgement must be made on an individual basis

Thus not only do strength and static endurance decrease with increase in age but the ability to perform and maintain activities requiring coordination of movements is impaired If decrease in strength truly reflects reduced musculature in the aged, then the reduction in ability for coordinated movements might be explained in terms of a decrease in the anatomical capacity for work If on the other hand reduced strength reflects a large component of neurological inadequacy, then functional and structural changes in the nervous system might be primarily responsible for reduced performance in older people

Oxygen Uptake (Intake) Responses

Valentin and his co workers (59) obtained values for average maximum oxygen uptake in normal subjects between 12 and 80 years of age The exercise was performed on a crank ergometer which involved the muscles of the extremities and trunk The work level was set by asking a subject to perform at successive work levels which increased by increments of 30 watts (30, 60, 90, 120, and 150 watts and so forth) On another day, the highest work rate which could be maintained for two minutes was performed and the measurements of oxygen uptake were made Mean values were obtained for 30 subjects in each 2 year age group from 12
in the double decade 20 to 40 years, and
year age spans up through 80 years of age
increased from 1 86 l/min in the 12 and 13 year old group to a maximum of 3 02 l/min in the 18 and 19-year old group and the 20-to 40-year-old double decade Average maximum oxygen uptake then decreased uniformly to 1 85 l/min in the 60-to-70-year old group and 1 60 l/min in the 70-to-80-year-old group In Fig 24 5(A) these values may be compared to those found by Robinson (46) for men running on a treadmill All of his subjects under 73 years of age ran at a rate which exhausted them in 2 to 5 minutes The average duration of these runs was in excess of 3 5 minutes In his subjects over 20 years of age, the maximum oxygen uptake values were consistently higher than those reported by Valentin However, discrepancies between these two sets of data of as much as one half liter per minute occurred only in subjects from 18 to 40 years of age Robinson did not attempt

exhausting exercise in his subjects between 73 and 78 years of age and the average maximum oxygen uptake for these 3 subjects agreed quite well with the average of 1 6 l/min reported by Valentin in the similar age decade

Dill (13) has reported the results of a longitudinal study of maximal oxygen uptake on himself from the age of 37 to age 50 A later report (14) ex

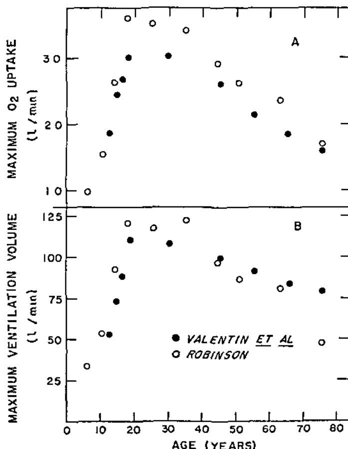


FIG 24 5 *Maximum ventilation volume* (B) *and maximum oxygen uptake* (A) *values* (*l/min*) *are plotted against age* (*year*) *for the experimental conditions of the data of* Valentin et al (• 59) *and the experimental conditions of the data of* Robinson (O 46)

tends this age range to 66 years Fig 24 6 shows these values The values up to age 40 show a level of maximal oxygen uptake of about 3 3 l/min This is followed by a gradual reduction to a level of 2 8 l/min at age 66

The responses of oxygen uptake to submaximal exercise of sufficient duration to permit metabolic equilibrium are summarized in Fig 24 7 The treadmill exercise data are summarized by solid lines The data of Pasar

gikhan, *et al* (43) for 18 subjects between 65 and 73 years of age give oxygen uptake responses for 7 work levels between 100 and 600 kg m/min (*B*) as well as for 10 work levels from 100 to 750 kg m/min in 5 25 year old subjects (*C*) The data of Robinson at 570 kg m/min are in good agreement with those of Pasargikhan for young subjects However, the rate of increase of oxygen uptake with increase in work rate is reduced at work rates above 450 kg m/min in the 65 to 73 year-old subjects of Pasargikhan (*B*) In this group the increase in oxygen uptake for an increase between 500 and 600 kg m/min of work rate is only 50 cc/min as opposed to 250 cc/min expected on the basis of the extrapolated curve (solid line) Robinson's data at 550 kg m/min of work is more nearly in agreement with the extrapolated curve The curve of oxygen uptake versus work rate has a markedly different slope for ergometer exercise (broken lines) The oxygen uptake responses are smaller for a given work rate than in the case of treadmill exercise Data are shown from both Astrand (1) and Ryhming (48) who have reported responses for oxygen uptake both in 20-to-30-year-old men riding a bicycle ergometer at 900 kg m/min and in 20-to-30-year-old women riding at 600 kg m/min *

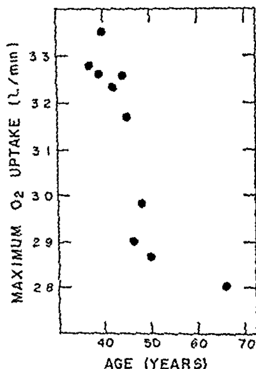


Fig 24 6 Maximum oxygen uptake (l/min) is plotted against age (year) for repeated measurements on an individual (12,13)

Similar oxygen uptake responses to exercise performed on manually operated ergometers have been reported for both young and middle aged adults by von Gessler and Markert (60) at a work level of 200 kg m/min and by Norris, Shock, and Yiengst (41) at work levels of 135 and 267 kg m/min In addition, our data on the 'maximal' type of exercise are included at 650 kg m/min for 22 young subjects and at 450 kg m/min for

* ... scand, 1958, 42, 73–86)

38 middle aged subjects Ghiringhelli and Bosisio (20) have studied the oxygen uptake responses to arm ergometer exercise at work rates from 75 to 725 kg. m/min in 32 "healthy" subjects aged 68 ± 3 4 years This wide range of work rates included high levels of work where older subjects might

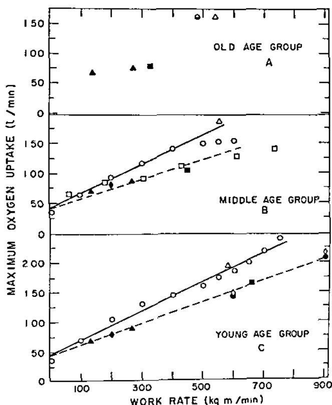


FIG 24 7 *Maximum oxygen uptake (l/min), attained at each of several levels of submaximal work, is plotted against work rate (kg m/min) for studies which have reported work of sufficient duration to permit metabolic equilibrium The data of Åstrand (•,1), Ghiringhelli and Bosisio (□,20), Norris, et al (▲,41), Pasargiklian, et al (○,43), Robinson (△,46), Ryhming (◇,48), Sartorelli and Scotti (⊖,49), and von Gessler and Markert (♦,60) are included In addition, the data for a one minute "maximal" type exercise are shown (■) Subjects are divided among young (C), middle (B), and old (A) age groups*

be suspected of having impaired oxygen uptake and low levels of work where older subjects have been shown to use more oxygen for a given amount of work (41) If we assume these factors are operating and use only the intermediate work rates of Ghiringhelli and Bosisio, we obtain a line

similar in slope and level to that for ergometer measured exercise responses in young subjects (broken lines)

The data for subjects over 70 years of age is more scarce However, in Fig 24 7(A) we may compare the oxygen uptake response data of Norris, Shock and Yiengst at a work rate of 135 kg -m /min with those of Robinson at 540 kg m /min and of Sartorelli and Scotti[8] (49) at a work rate of 475 kg m /min in their subjects aged 80 to 89, 73 to 78, and 70 to 78 years respectively A line drawn between the coordinates of oxygen uptake versus work rate for these bodies of data has the same slope and level of oxygen uptake response as do those of the treadmill data on the two younger groups of subjects

Thus there is no evidence for a difference in submaximal oxygen uptake response for subjects of different ages There is, however, a marked difference in the curve of response of oxygen uptake versus work rate for treadmill exercise and the curve of oxygen uptake versus work rate for exercise on the ergometer There are several possible reasons for this difference First, more of the total work done may be measured by the ergometric technique We know from the data of Coates, *et al* (10) that the work of raising the body up and down with each step during walking is not calculated by merely measuring the average lift of the body on an inclined treadmill, as was done for these calculations Work rates calculated in this way would be systematically low because we have not considered the up and down movement of the body with each step Although there are similar losses in most ergometers, they might be expected to be less Therefore the net effect would be to measure a greater proportion of the total work in ergometer exercise and thereby to produce the observed lowering of the rate of increase of oxygen uptake per unit increase in work rate It is of interest to note that our data on subjects comparable to those of Ghiringhelli and Bosisio indicate that the responses for our conditions of the maximum work rate that could be maintained for one minute were comparable to theirs for metabolic equilibrium

Oxygen uptake during exercise has been modified in older subjects by the omission of breakfast Tuttle and co-workers (56) maintained 8 men (62 through 83 years of age) on a prescribed diet which supplied one fourth of the daily requirements of the essential foodstuffs, as well as calories After eating three meals a day for four weeks, breakfast was omitted for four weeks All of the 8 subjects had a higher oxygen uptake for treadmill walking (2 percent grade at 2 miles per hour) during the no breakfast period Six of the eight subjects showed statistically significant ($P = <.06$) increases during the no-breakfast period These authors have not provided compa

[8] Sartorelli and Scotti had 10 subjects who worked at several different levels of exercise, as was the case for other data reported The highest level of work could only be surmised as the limit of the specifications of the exercise The lower levels were not identified with specific relation to metabolic or ventilatory responses

rable data for younger subjects However, Simonson (51) has summarized data collected by his co workers which indicate that the rate of oxygen uptake by young men during walking on a treadmill at 3 5 miles per hour is not changed during the first day of fasting Indeed, young subjects who had been on a "standard diet for 2 weeks prior to the starvation showed a decrease in the oxygen used for walking at 3 5 miles per hour during the third fasting day

VENTILATORY RESPONSES

The ventilatory responses to the levels of work used by Robinson (46) and by Valentin and his co workers (59) are quite similar Their data are shown in Fig 24 5(*B*) In both cases the highest responses occurred in subjects between 18 and 40 years of age In Valentin's data, the age decade means showed a very regular decline after age 30, from 108 l/min to 79 l/min in the 70-to-80-year-old group Robinson's data are in good agreement with these values, except for his 10 32 to 38 year old subjects who had a somewhat higher response than similar subjects of Valentin, and his 3 73 to 76-year old subjects who showed a markedly lower response of ventilation than the subjects of Valentin It should be noted that the maximum breathing capacity values reported for older subjects (38) are somewhat lower than the maximum ventilatory response to exercise reported by Valentin

A summary of the ventilatory responses to submaximal work is presented in Fig 24 8 The curve for ventilation volume response versus work rate may be corrected to account for differences in estimates of treadmill and ergometer work rate by adding to the nominal work rate the appropriate difference as shown in Fig 24 7(*B*) or 24 7(*C*) If this is done, the ventilatory responses to the treadmill walking data of Pasargiklian, *et al* (43) and of Robinson (solid line) and the bicycle pedaling data of Astrand (1) and Ryhming (48) (broken line) are quite similar If a similar correction is performed for the middle aged group (Fig 24 8 *B*) where results from both treadmill and arm ergometer exercises are available, the treadmill data of Pasargiklian, *et al* and of Robinson become more like the ventilatory responses to the step test of Thomas, *et al* (54), and lower than the ventilatory responses to arm ergometer exercise as measured by Ghiringhelli and Bosisio (20), and Norris, Shock, and Yiengst (41) The data for subjects over 70 years of age (Fig 24 8, A) are not adequate for such comparisons In this group, and in the middle aged group, our results for ventilatory response to the maximum work rate that was maintained for one minute are as high as the others summarized here When a similar test is applied to the young age group (Fig 24 8, C), however, the ventilatory response is as much as 20 l/min higher than the data for equilibrium situations This suggests that in the young subjects there is a larger response of ventilation in the early adjustment to exercise than in the older subjects

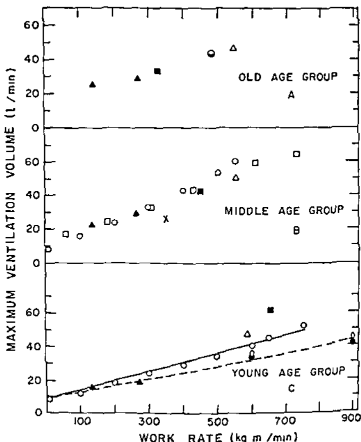


FIG 24 8 *Maximum ventilation volume (l /min), attained at each of several levels of submaximal work, is plotted against work rate (kg m /min) for studies which have reported work of sufficient duration to permit metabolic equilibrium The data of Astrand* (●,1), *Ghiringhelli and Bosisio* (□ 20), *Norris* et al (▲ 41), *Pasargiklian,* et al (○,43), *Robinson* (△ 46) *Ryhming* (◇ 48), *Sartorelli and Scotti*

■

old (A) *age groups*

Cardiovascular Responses

The highest heart rate attained during maximal work in Robinson's subjects (46) decreased with age from about 200 beats/min at 20 years of age to about 160 beats/min at 70 to 80 years of age Dawson's longitudinal data (12) also show a decrease in heart rate with increase in age from a maximum of 180 beats/min at age 53 to a maximum of 140 beats/min at age 71 Dill (13,14) had a decrease in maximum heart rate from 172

beats/min at age 37 to 160 beats/min at age 66 Durnin and Mikulicic (16) have compared the heart rate responses of 12 subjects, 20 to 29 years of age and 12 subjects 55 to 67 years of age, both for arm ergometer exercise and for treadmill walking The responses to two levels of arm ergometer exercise were similar for old and young, while the older subjects showed a greater response to two levels of treadmill walking exercise (oxygen uptake = 1.45 l/min and 1 18 l/min) However, both the data of Norris, Shock, and Yiengst (40) and the data of Ryhming (48) have shown that during exercise at work levels which were less than maximal, subjects of greater age had greater heart rate responses In the former study, stepping work was performed at a rate of 150 kg m/min by 142 subjects between ages of 20 and 92 years In the latter, 25 male steel workers between 41 and 65 years of age performed both a bicycle ride at 600 kg m/min and an equivalent stepping test

Robinson does not report the results for the blood pressure measurements made on his subjects, so we may assume that there were no significant age differences at the levels of work he used Moreover, age differences in blood pressure responses are not apparent in Dawsons s longitudinal data At the intermediate levels of work used by Durnin and Mikulicic, systolic blood pressure was somewhat higher in the old subjects after exercise, while Norris, Shock, and Yiengst found a greater increase in the systolic blood pressure of older subjects

Data on age differences in cardiac output during exercise are even more scarce than data for the aforementioned cardiovascular measures Mori (36) has reported cardiac output measurements before and after exercise in 11 subjects from 17 through 57 years of age His data indicate that after exercise *there is a lesser increase in cardiac output in subjects of greater age* Data that we have collected for 8 subjects in each of the 6th 7th, 8th, and 9th age decades for a work rate of 135 kg m/min may be compared in Fig 24 9 with those of Donald and co workers (15) for 7 20-and 30 year old subjects working at similar work rates Although the subjects in both studies were recumbent, our subjects used arm exercise and Donald's group exercised by pedaling a bicycle ergometer with their legs In both studies cardiac outputs were measured during the third minute of exercise The cardiac output responses of Donald's subjects working at rates of 100 and 200 kg m/min averaged 2 1 and 3 7 l/min respectively, while our age decade mean values ranged from 2 4 to 3 0 l/min Thus young and old subjects give quite similar results for cardiac output response to submaximal exercise

Robinson s data indicate that after one minute of exercise his oldest subjects attained a slightly smaller percent of their maximum heart rate than did the young when work was performed at the maximal level An even smaller percent of the maximum heart rate attained during work was reached by the older men one minute after starting work at a more moderate rate Robinson s data for heart rate, and the data of Norris, Shock, and Yiengst

for both systolic blood pressure and heart rate indicate that there is a delay in the recovery of these responses after exercise Durnin and Mikulicic also showed a delayed recovery of heart rate after both arm ergometer and treadmill exercise, although they did not find these differences to be statistically significant However circulatory recuperation was significantly slower in the elderly during later recovery (3rd through 10th minute) after walking at 4 3 miles per hour

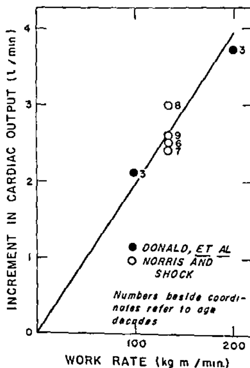


FIG 249 *Increment in cardiac output (l/min) is plotted against work rate (kg m/min) for young subjects of Donald, et al (•,15) and old subjects of Norris and Shock (O,37) Numbers beside coordinates refer to age decades*

Mechanical Efficiency

Data for moderate levels of work (300 kg m/min to 600 kg m/min) have failed to show differences with age in mechanical efficiency Net mechanical efficiency values average from 15 to 18 percent for the data of Sartorelli and Scotti (49), Robinson (46), Pasargiklian and coworkers (43), Ghiringhelli and Bosisio (20), and Norris, Shock, and Yiengst (41) up to values of 22 to 25 percent for the data of Ryhming (48) and of Burger and Hause (8) The wide range of values undoubtedly results from uncertainties in estimating the amount of external work performed Von Gessler and Mar... from 16 to 25 percent and were higher than others reported at the low work levels used by them (about 200 kg m/min) However, at similar low work levels (below 300 kg m/min work rate) Norris, Shock, and Yiengst have found decreased mechanical efficiency in their subjects over seventy years of age, especially at a work rate of 135 kg m/min This difference was based on the fact that for intermediate levels of work, the oxygen uptake for old and young subjects was similar, while at low levels of work the oxygen uptake was significantly higher in the older subjects than in the young Subsequent studies by Norris and Shock (37) indicate that half of the extra oxygen used by their oldest subjects (65–89 years old) was ac-

counted for by their failure to take up oxygen at as high a rate as the young during exercise

RATE OF RECOVERY OF PHYSIOLOGICAL EQUILIBRIUM FOLLOWING EXERCISE

Berg (5) has shown age differences in the rate of recovery of oxygen up take and CO_2 elimination following an exercise of 20 steps per minute onto a 9 inch high platform for 3 minutes He performed duplicate tests on 33 subjects between 17 and 60 years of age The data analysis consisted of plot ting the logarithm of oxygen uptake and CO_2 elimination versus time for the first 2 minutes following exercise, and determining the half recovery time *from a line fitted to these data* He found *that* the recovery time constant for CO_2 elimination increased from 35 seconds for subjects 20 years of age to 60 seconds for subjects 60 years of age, while the recovery time constants for oxygen uptake were increased from 28 seconds at 20 years of age to 35 sec onds at 50-60 years of age

Baldwin, Cournand, and Richards (3) have presented their data as average values for three groups of subjects of different ages Group I sub jects were 16 to 34 years of age, Group II subjects were 35 to 49 years old, and Group III subjects were aged 50 to 69 years in the case of the men and 50 to 79 years in the case of the women Average values for each measure ment in each age group included from 15 to 19 men and from 10 to 17 women The exercise was stepping up on a 20 cm (7 7/16") platform, placing both feet up and down thirty times in one minute Although the ventilation volumes were higher for the older subjects than for younger, there was no indication of an age difference in rate of recovery based on estimates of ventilation volume for the first, second and fifth minutes fol lowing exercise The oxygen consumption during the fifth minute of re covery was still above basal levels in the older men, while the young men and all the women returned to basal levels of oxygen consumption by the fifth minute of recovery

We have compared the rates of recovery of oxygen uptake, CO_2 elimi nation, and lung ventilation following exercise in 70 subjects from 20 to 89 years of age There were 10 subjects in each age decade The submaximal work rates used ranged from 135 to 450 kg m /min and were performed for 1 to 4 minutes The average levels of responses during exercise and rates of recovery for 10 minutes after exercise were compared for young and old

of displacement produced On the other hand, the responses of lung ventilation to exercise were significantly higher in the old than in the young, and the rate of recovery of lung ventilation was faster in the older subjects than in the younger subjects The increased response of lung ventilation is attributed to inadequacies of the older pulmonary system (such as mixing

difficulties, poorer diffusion, and reduced perfusion) which necessitate increased ventilatory response to provide adequate oxygen supply to the blood The more rapid decrease of lung ventilation in the old is attributed to increased rigidity of the lungs and chest cage. These interpretations assume that it is possible, in the old subjects, to have a more intense stimulus which is remitted more rapidly than in the young The somewhat higher responses and faster recovery of CO_2 elimination in the old prevent its invocation in explanation of the age differences in ventilatory response A more acceptable description of the stimulus would be one which included a large component that varied with the level of exercise (absent during the resting period, present during the exercise, and absent during the recovery period) The complete remission of this component at the end of exercise would thus emphasize the contribution of age differences in rigidity of the lungs and chest cage

Thus there are differences in rates of physiological adjustments which could conceivably be responsible for poorer over all function in older subjects The exact relationship of differences in individual functions to overall function has not been demonstrated However, Norris and Shock (37) have suggested that one of the major causes of reduced mechanical efficiency seen in their oldest subjects lies in the failure of the old subjects to take up oxygen at as high a rate as the young during exercise This results in larger, less efficient anaerobic utilization of oxygen in the older subjects

Since not all of the extra oxygen used by the oldest subjects is accounted for in this way, more basic failures of coordination, such as changes in muscle contraction timing might also be involved in the aging process.

Age Changes in Coordination

Operation of a bicycle type of ergometer, manually, at a prescribed rate, involves accelerating and decelerating the system so that the average

contractions can usually be noted in the work records as periodic irregularities in work rate

In young normal subjects bi manual exercise of this type is performed so that the work rate is relatively constant and the amplitude of these irregularities is small In older subjects, however, the amplitude of these fluctuations is larger although the average submaximal level is maintained equally well in old and young Fig 24 10 shows this variability expressed as the range of work rates observed during a four minute bout of submaximal exercise for both young and old subjects This test was compared with

who were not permitted strenuous exercise because of clinical findings A comparison of these with subjects accepted for strenuous exercise indicates that the variability is reduced in the oldest subjects who were accepted for the strenuous exercise

Earlier comparisons of motor performance in old and young subjects made by Miles (31,32,33) and by Bellis (4) indicate that there is a psychomotor basis for the decreased coordination ability shown here More recent studies of changes in reaction time (6,21,42) have confirmed these findings Norris, Shock, and Wagman (39) have demonstrated significant decreases in human motor nerve conduction velocity with increase in age Although the magnitude of this decrement is small compared with changes in psychomotor performance, the changes suggest the presence of a physiological (neuromuscular) basis of decreased efficiency

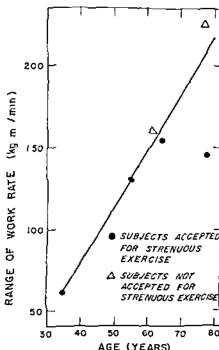


FIG 24 10 *Range of variation of work rate (kg m /min) during four minutes of a manual cranking exercise (nominal work rate = 135 kg m /min) is plotted against age (year) for two classes of subjects (1) Subjects who were excluded from strenuous exercise on the basis of a clinical examination (△) and (2) subjects who were accepted for strenuous exercise on the same basis (●)*

AGE DIFFERENCES IN FITNESS TEST PARAMETERS

The physiological measurements already reviewed provide the most fundamental estimates of physical fitness However, the techniques and equipment associated with some of these tests are not readily available in the doctor's office or in the gymnasium As a result many less complicated tests of physical fitness have been proposed These tests have ranged from evaluating the anatomical characteristics of an individual (such as vital capacity and muscle strength) to evaluating the dynamic responses of some physiological parameters during or following a standardized exercise Physical fitness tests have been used in classifying candidates for college physical education programs and military service as well as the evaluation of patients in the doctor's office Fitness tests have appeared in a wide variety of forms, but most involve measurement of pulse rate or blood pressure be

fore and following some standardized exercise (7,11,17,18,22,24,35,50 55 57) The McCurdy Larson test (30) requires measurements of breath holding time and vital capacity as well as heart rate and blood pressure

At the present time, most physical education teachers prefer performance criteria for the evaluation of physical fitness They measure parameters such as strength agility, speed, and endurance Endurance may be either the type involved in running or swimming, or large muscle endurance such as that involved in sit ups and pull ups In addition, some tests include estimates of flexibility of the trunk and joints Examples of tests utilizing these parameters are the Army Air Force Physical Fitness Test and Larson's Motor Ability Test A few studies have considered postmaturity age in relation to this type of physical fitness test Karpovich and Weiss (25), Larson (26), and Loveless (27) have reported decrements in performance over the age ranges 18 to 38 years, 21 to 48 years, and 18 to 35 years, respectively These decrements ranged from 10 percent to 43 percent

Strenuous tests are considered inappropriate for people above 45 years of age who have not maintained physical conditioning The physician, examining patients in this age range, most often uses a stepping exercise and measures the response and recovery of heart rate and blood pressure or electrocardiogram Age comparisons have been made for this type of test

Norris Shock, and Yiengst (40) have reported age differences in the responses of both heart rate and blood pressures to a standard step test exercise The subjects walked over two 9 inch steps (total height 18 inches) the number of times required by each subject to perform 222 kg m (S D

a chair after exercise in a standing position For control purposes these observations were compared with observations made on the same subjects who sat in a chair after quiet standing One hundred and forty ambulatory male subjects, between 20 and 92 years of age, were used for these experiments It was found that older subjects increased their systolic blood pressure levels more after exercise and returned to pre exercise levels later than did younger subjects There were no age differences in diastolic blood pressure responses after exercise However, the heart rate increased more and reached postexercise levels later in the old than in the young subjects The authors concluded that there was a slowing of cardiovascular recovery processes following exercise in old subjects, as compared to young subjects

Master (28) has reported an exercise tolerance test for circulatory efficiency His "two step" test consisted of having the subject climb two 9-inch steps (total lift = 18 inches or 0 46 meters), which are arranged so that the subject goes up two steps and down two steps, turns and goes back the

other way His criterion of efficiency was the return of heart rate and blood pressure to pre-exercise levels in two minutes following exercise On this basis, he arranged tables of the amount of work that could be done by normal people of various weights and various ages Any subject who had a pulse rate or blood pressure value greater than 10 points above resting 2 minutes after exercise was considered abnormal His tables are the results of more than 2000 tests performed at Cornell University Medical College on normal persons of all ages and both sexes Fig 24 11 is a summary graph of

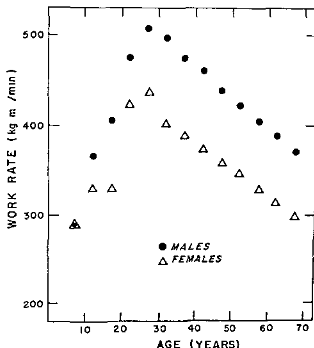


FIG 24 11 *Maximum work rate (kg m /min) which permitted heart rate and blood pressure recovery in two minutes is plotted against age (year) from the data of Master* et al (28) *Males* (•) *and females* (Δ) *are shown separately*

these data For both men and women the number of trips increased to a maximum between 20 and 35 years of age There was, however, a slight variation in these maxima with change in weight, the heaviest subjects showed their maxima between 25 and 35 years of age, and the lightest subjects showed their maxima between 20 and 30 years of age The heaviest subjects were between 200 and 230 pounds and the lightest subjects were between 80 and 100 pounds, except for the children who ranged as low as the 40-to-49-pound weight group

The curve of age versus work rate, originally plotted in Master's 1929 report (29), bears a striking resemblance to the curves of age versus tests of motor speed which have been reported by Miles (31) It is reasonable that this may be so, for in Master's test, the speed of recovery of the cardiovascular measures limits the amount of work done, or the number of trips across the steps Thus if the speed of recovery is slower in the older subjects then the number of trips or the amount of work done may be less than in the young for an equivalent recovery time Norris, Shock, and Yiengst have also reported slowing of recovery of cardiovascular displacements with increase in age Their data included older subjects than those reported by Master In addition to the exercise data, they reported slower responses of older subjects to changes in posture which were induced by a tilt board These results may be interpreted as confirming the fact that the changes in blood pressure and heart rate due to changes in posture do not have any systematic effects which alter the results of the test as proposed by Master

PROBLEM AREAS TO EXPLORE

Our concepts must be broadened to include age as a variable in the total picture of human performance In addition to the basic functions which have been studied and summarized here, we should examine the underlying physiology of body movement and control

We need to know more about the age changes in body mechanics, the effects of changes in neuromuscular function, and the effects of changes in the integrative activities of the nervous system Continuous performance results in a decrement in speed and coordination The general name given to these signs is fatigue Both the concept and its age relations should be examined

The problems of coordination of cardiorespiratory responses to various types of stress such as exercise are in great need of clarification Studies of rates of response and recovery of these physiological measures during and after exercise have largely been by products of studies of other parameters Studies of the relative rate of change of even cardiovascular, ventilatory, and metabolic functions are virtually nonexistent

The effects of training on older people have not been tested by adequate physiological

lesser activities even beyond that age This leads us to consider the possibility that older people who have become inactive, and by that token incapable of even the normal everyday activities, might, with proper motivation, be retrained to conduct their everyday routine

Whether your interests are athletic, medical or custodial you must deal

with man all his life The problems of the years after 50 have created a need for knowledge which has not been satisfied The door is open

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ELSWORTH R BUSKIRK
AND J E COUNSILMAN

Special Exercise Problems in Middle Age

SUMMARY

Physiological age, while a desirable concept, is difficult to establish for a given individual It has been emphasized elsewhere (38) that different physiological ages characterize each organ and each physiological function in the same individual and that there are marked individual differences in the rate of aging For the time being, until integrative methods are well established, it is simplest to define middle age limits by an arbitrary chronological age range, i e, 30–55 years Most of the discussion has been confined to this age period

Attention should be drawn to the fact that the subject field for this chapter was exclusively middle-aged males This illustrates the almost complete lack of information about exercise participation and exercise tolerance by middle-aged females

Numerous middle aged men participate enthusiastically and profitably in professional sports Many of the contestants in the Olympic games are middle-aged The sports in which middle-aged participants have performed best are discussed, although the reasons for superior performance by the middle-aged in a given event remain obscure

Although age trends in physical performance have frequently been observed, an attempt should be made to view these trends in proper perspective by taking into consideration factors such as body composition, physical conditioning training, pathology, etc The trained man usually performs best in a given age group and therefore sets maximal values Because of the nature of some performance tests, measurable performance may only be achieved by the trained individual which biases all age related information

Middle-aged men have been observed to be as fit and able to perform hard work in hot environments as younger men, however, their physiological re

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Middle-aged men have been observed to be as fit and able to perform hard work in hot environments as younger men, however, their physiological re

sponse to heat is rather different, i e, a sluggish response to thermal stimulation

A pressing nutritional problem has become closely identified with middle age—obesity A body of evidence has been accumulated, largely by Mayer and co workers,[1] that physical activity deserves more than passing consideration in solution of this problem

The role of habitual participation in exercise in relation to the development of chronic conditions particularly cardiovascular disease, is not well known The evidence in the literature is speculative and inconclusive, although medical opinion favoring suitable exercise as both preventive medicine and therapy seems to be growing

Individuals from all walks of life have publicly proclaimed their philosophy of exercise in the popular press One can easily obtain "authoratwe' documentation either for or against participation in recreational activities, exercise and sports A body of evidence is accumulating, however, which indicates that most exercise is well tolerated by "healthy" middle aged males provided a judicious approach to and selection of physical pursuits is employed

The psychological and social benefits accrued during middle age through participation in exercise and recreational endeavors may be equally as important and more easily documented than physiological benefits Since it is probable that the synergism of psychological, social, and physiological factors produce gains," a wisely selected exercise program may contribute measurably toward productive life in middle age

INTRODUCTION

The chapter by Norris and Shock Exercise in the Adult Years—with Special Reference to the Advanced Years' describes in detail various age-related changes in physical performance capacity and ability together with an excellent discussion of concomitant physiological function The middle age years are adequately discussed by these authors, however, it is felt that certain exercise problems, seemingly characteristic of middle age, should be given special treatment The material presented is selective rather than comprehensive

Ho [illegible]

a sedentary population—do they? What fraction of positions and/or occupations may be classed as sedentary? What about capacity and ability to participate in games, contests and recreational sports—does a man of 40 participate more or less frequently or extensively, with greater or less health

[1] See chapter 16, Exercise and Weight Control '

risk, than in 1900 or 1920? How can we quantify physical performance abilities in middle age in the year 1958? How is frequency and duration of performance of what kinds of exercise related to general health? Can the established age trends for some of the chronic diseases, currently prominent during middle age, be altered by exercise? Is the "physically fit" person more or less likely to succumb to the degenerative diseases of middle or old age?

Numerous other questions could be asked Some partial answers are available, but unfortunately the majority of these and related questions go unanswered The interested graduate student and/or investigator take note—here indeed is a fruitful field

Before discussing what little is known about special middle age exercise problems, it would be well to emphasize the paucity of longitudinal information By longitudinal is meant continued observation of the same population over a period of years In relating physiological function to age, a significant part of the picture is missing without longitudinal studies Perhaps a plea should be extended at this time for more planning on a longitudinal basis so that investigators surveying this field in 1980 or 2000 have more to recite than findings referrable only to different populations in each age group

CLARIFICATION OF TERM MIDDLE AGE

The process of aging progresses at varying rates in different organs and also in different persons (38) For this reason it becomes difficult to accurately assign a certain chronological age as the beginning or end of the

hronological age

be determined in

a valid manner through objective means The importance of the difference between chronological and physiological age cannot be overemphasized A man of 55 may be biologically younger and capable of higher levels of physical performance than another 15 years his junior

Since physiological age is difficult to assess (although considerable progress has been made in recent years), the "easy" way out has been taken, and the middle years have been defined in terms of chronological age Age 30 to 55 has been arbitrarily selected as "middle age" For the most part, subsequent discussion will be confined to this age period

PERFORMANCE OF THE MIDDLE AGED IN ATHLETICS

Performance in athletics in the United States is frequently conceded to be in the realm of the young adult while the middle aged person is relegated the role of spectator and wishful thinker Nevertheless, numerous middle aged United States "youths" do participate in athletics and frequently per-

form both effectively and spectacularly A brief analysis of age in relation to performance in the middle years is presented to illustrate the point that many middle aged men are exceptionally active physically and can perform in some sports at levels unexceeded by any other age group

The perspective gained by considering the age of optimal performance in professional athletics (and in sports where a strict amateur code is not fol lowed) is one referrable to individuals who have undertaken a continuous measure of training in the task used to evaluate their performance i e their respective sport Thus a unique population is viewed The segment of the athletic population—American amateurs —are excluded from con sideration because the lack of financial gain usually shortens the amateur s career The common denominators in performance namely motivation skill fitness and condition are not all controlled and alter age trends even in selected groups of professional athletes Thus tabulation of the age at which professional athletes achieve their greatest performances presents only one but nevertheless an interesting picture of optimal age in relation to athletic performance

Lehman in two publications (27 28) has summarized age trends in various professional sports These publications should be consulted directly by the interested person because only a few selected sports in which the middle aged persons do well are cited here Table 25 1 presents selected statistics compiled by Lehman from records of Major League Baseball Although the statistics are somewhat dated pre 1936 and 1946 the results if anything probably underestimate the number of over 30 players active today The mean age for the various champions and the most valuable player listed in Table 25 1 is under 30 (28 or 29) but at least 30–40 percent of the age distri

TABLE 25 1 Selected Summary of Findings Major League Baseball*

Type of Activity	No	Median Age	Mean Age	SD	Age Maximally Proficient
Annual batting champions to 1936	96	29 00	29 16	3 46	26–29
Annual pitching champions to 1936	88	28 25	28 18	3 72	26 31
Home run champions to 1946	*81*	*28 15*	*28 87*	*4 08*	*26–29*
Most valuable player to 1946	79	28 25	28 84	3 49	26–29

* From Lehman (28 Table II p 167)

the Interleague Champion Milwaukee Braves to be reminded how active middle age players can be

Table 25 2 from Lehman lists several sports in which [illegible] have done exceptionally well Not all of the sports listed are [illegible] sports Tennis, race driving, and corn husking require speed [illegible] well as skill Contact sports do not appear in the list, however, [illegible] sional football and ice hockey players compete successfully [illegible]

TABLE 25 2 Proficiency in Various Sports*

Sport	No of Cases	Median Age	Mean Age	Standard Deviation [illegible]	[illegible]
U S professional tennis championships	21	29 25	30 88	[illegible]	[illegible]
Indianapolis Speedway racing championships	82	29 47	30 12	[illegible]	[illegible]
National corn husking championships	17	32 83	32 26	[illegible]	
Miscellaneous bowling events	303	33 90	34 68	[illegible]	[illegible]
Rifle and pistol shooting championships	630	31 24	32 05	[illegible]	[illegible]
Billiards (world championship performances)	136	33 00	34 35	[illegible]	[illegible]
Professional golf championships	63	32 50	32 58	[illegible]	[illegible]

* From Lehman (28 Table VI p 174)
Data were included if either median or mean age exceeded 30 [illegible]

of 30 and 40 In general, events requiring little in the way [illegible] strength, power, agility speed, and a high level of neuro[illegible] tion seem best suited to the middle age competitor (golf, [illegible] etc)

Because of the large number of contestants and the high [illegible] ance, the Olympic Games have been frequented on num[illegible] statisticians, physicians, and exercise physiologists The [illegible] participants have been reported fairly regularly (19 20,[illegible] lists three events in which middle age contestants [illegible] 1920–1936 games

A summary of the age distribution of the 1952 Oly[illegible] been prepared by Jokl (20) The mean age of the partic[illegible] or more in the following events dressage, shooting [illegible] Grand Prix, epee, 50 km walk, over 90-kg weight lifti[illegible] 87 kg Greco-Roman wrestling Three-Days event, [illegible] wrestling, 10,000-meter walk, foil, 73 kg free style wrest[illegible] meter run In endurance events, particularly in track a[illegible] central tendency (mean) of the age distribution occur[illegible]

age Jokl noted that this trend did not occur in endurance cycling or swimming events The question might well be asked—why? Is the age difference between types of endurance simply a result of "favorite" sports participation and social background in various geographical areas and not a result of "optimal physiology" for specific endurance events at a given age?

The age distribution of the 1952 Olympic athletes—4823 individuals—

TABLE 25 3 Age of U S Contestants in the 1920–1936 Olympic Games*

Event	No	Median Age	Modal Ages
10 000 Meter Race and Marathon	25	31 50	26–30
Bob Sledding	36	34 25	30–34
Equestrian Events	39	36 42	32–36

* From Lehman (28, Table VII p 185)

was studied by the International Olympic Committee (19), and its conclusions were set down in an article entitled *Research on Olympic Athletes* "The span of years between the ages of the youngest and the oldest competitors amounted to more than four decades—in some events a preponder

were comparatively high, and vice versa"

This statement emphasizes the considerable variation in age between competitors in most Olympic events The tables from Lehman also clearly indicate the wide distribution in the age in which optimal performance occurred Therefore compilation of events in which middle age competitors excel gives a limited view of the actual potential of the middle age athlete,

and the middle years (age 30–33 in the 10,000-meter and marathon—see results of Olympics cited previously) Since Finnish athletes compete in sports almost exclusively for fun and recognition and continue relatively late in life with no school or university affiliation, Karvonen's studies may be somewhat more meaningful in terms of describing "true" ability in middle

age than similar studies of amateur or even professional athletics in the United States

We have all been impressed in recent years with the extended success of athletes in their 30's and 40's and even 50's Boxing events frequently display the talents of Sugar Ray Robinson and Archie Moore Individual baseball championships fall to the likes of Stan Musial and Ted Williams The golfing world often bows to the superiority of a Bobby Locke, Sam Snead, Jimmy Demaret, and Ben Hogan Lou Groza in football, Don Budge in tennis, Willie Hoppe in billiards, Joe Hiestand in trapshooting—the list could go on and on Are these individuals special physiological specimens who spurn "normal" aging trends? Are they extremely dedicated to their respective sports and overcome 'normal' aging through sheer drive? Seeking answers to these and related questions should provide ample opportunity for the researcher interested in sustained peak performance in relation to both aging and "normal" physiological function

A question was asked in the introduction about how the middle age man of today compares with his early 20th century counterpart from the point of view of physical performance capability Although the time span covered in the study by Jokl (18) is 1928–1952, or only 24 years, the results may apply to longer time spans Jokl compared the performance of well over 1000 athletes at the Deutscher Turner Bund contests in 1952 with that in 1928 The maintenance of performance with age was improved in 1952 over that of 1928 for at least three exercises 75 meter dash, shot put, and jumping The contestants of age 49 in 1952 were able to equal the performance of 40-year-old contestants in 1928 Although changes in such factors as skill, technique, practice facilities, and practice time could have influenced the results, there is strong implication of a biological factor

BODY COMPOSITION AND INTERPRETATION OF PERFORMANCE TESTS

Two of the chronic problems seemingly characteristic of middle age, i e, sedentary living and obesity, confuse interpretation of results obtained on physical fitness and performance tests in this group Not only is motivation low in middle age, but muscular mass has decreased in comparison with young adulthood, and body fat has been gained In addition, performance skill is partially lost, strength is reduced, and cardiovascular "reserve" may be lessened Aerobic work (oxygen debt never becomes critical) is performed at about the same energy expenditure level by the middle aged as by younger men (may be higher in middle aged men), but the cost per unit mass of "active tissue" must be higher because of the proportionality of total energy expenditure to total body weight (36,14) The obese middle aged man is under a considerable handicap in work requiring sustained effort at rela-

tively high work levels because of his load of fat, to say nothing of the additional restrictions of motion produced by his fat masses At a given work level the obese person is usually working nearer capacity than a nonobese individual of equal weight

ingful The decrease in aerobic capacity or reserve as measured by the maximal oxygen intake may not be as marked however, if expressed per unit of fat free weight or active tissue Maximal oxygen intake per unit of active tissue would

tory cardiovascular

The question is c

liver sufficient

active tissue

inactive men

produce an extra stress on the cardiovascular system during exhausting work but does make the accomplishment of a fixed work task (such as running a mile) more difficult (6)

A rough estimate of the decrease in aerobic capacity during the middle years may be made by combining information from two sources i e the data

age 25 2 years (n 25) and mean weight 70 6 kg the percent body fat computed from specific gravity was 14 4 percent (10 2 kg) On the other hand

a rough estimate, what amounted to a 20 percent reduction in aerobic capacity

tion to the excellent longitudinal information that he and others have already collected on himself

Motivatio

investigators

middle age

in middle and older age groups unless objective tests are used in which

motivation is not a factor Astrand (3) has questioned peak performance in Robinson's work largely because duplicate or triplicate testing was not performed on the older individuals In defense of Robinson, essentially the same age trends have been consistently observed in middle age when the maximal oxygen intake test has been used (13,33,47) Astrand's criticism, while justified at the time perhaps, has not been substantiated by subsequent research One should be extremely skeptical, however, of using performance tests for middle aged men which are dependent on subjective end points (step tests, etc) because of the distinct possibility that motivation is indeed rather poor

Training involving running and hard work, other than strength maneuvers, appears to reduce pulse response to exercise regardless of age (2,9) Although the effect of training may appear to be "clear cut," the pulse response to submaximal or even near maximal work is in part weight dependent if an appreciable portion of the weight is carried as excess, *i e*, fat or obesity tissue (7) Since weight reduction and loss of body fat frequently accompany training progress, the total change in pulse response to exercise reflects both a training effect and the reduction in total work done in stepping (step test) or on the treadmill Weight reduction and body fat loss with training may be more readily realized in the middle aged group because of the tendency toward overweight and obesity in this group

ENDURANCE

An interesting series of investigations on maximal work capacity as related to "endurance," rather than aerobic capacity exclusively, was performed by Dawson (11) Dawson served as his own subject for the experiments, which started in middle age and covered the age range 41–71 The work performed was riding a bicycle ergometer at the heaviest work load that could be accomplished in 30 minutes The conditioning exercises varied (three [illegible] mbing, cycling) prior to the tests at each [illegible] at ages 41, 57, and 71 was comparable, [illegible], the total kilograms of work performed at those ages are the most meaningful The values were 55,000, 33,074 and 28,600 kgm, respectively The value obtained at age 41 (55,000 kgm) was an estimated value based on an 18-minute ride during which 38,654 kgm of work was performed The conservative extrapolation to 30 minutes gave [illegible] 60 percent of that at age 41 [illegible] noted—the recovery time between maximal exertions increased with age Since some training was performed at all ages a peculiar effect of training at any given age was not uncovered Suffice it to say that training of the type used by Dawson did not prevent a decrement in endurance associated with age, however, at age 71 he could perform work at levels few elderly peo-

ple could duplicate Dawson's findings have been corroborated by Simonson (39,40) who found that the running endurance of 11 men of average age 53 was about half that of 25 men of average age 33

It is interesting to note that the decrement in endurance associated with age exceeded the decrement in aerobic capacity as estimated by the maximal oxygen intake Simonson (39,41) has speculated about this difference and has suggested that greater heart strain is involved in endurance exercise and a greater depression in excitability of the central nervous system (as assessed by Flicker fusion frequency) may accompany endurance exercise Another factor may well be the considerable metabolic stress of endurance type exercise as compared to short term running The "metabolic reserve" may also be considerably reduced in older men as indicated by reduced mobilization of energy stores (37)

Blood Pressure

Resting blood pressures quite commonly rise slightly in men and in women as they pass the age of 40 (1,44) Although this trend has been observed, considerable interindividual variation exists and many investigators have reported no systematic age trend

Few changes in blood pressure that are attributable to exercise have been

ing Neither of the latter two studies appear to be confirmed.

The relationship of chronic participation in exercise to the incidence of hypertension has not been adequately pursued, probably because of the multiplicity of gross contributory factors such as diet, environment, emotional climate, genetic background, and disease

One acute effect of exercise as related to middle age has been observed During performance of submaximal exercise, systolic pressure tends to be higher and recovers slower with advancing age (35)

Heat Tolerance in Middle Age

The most likely time for "average" middle aged males to be active physically is in the warm months of the year Gardening looks attractive, lawns need mowing, and children lure parents into games On some days the dry and wet bulbs reach values where heat tolerance should be considered in

In a systematic examination of tolerance time, ability to perform moderate work (simulated mine rescue operations which were carried out on a fixed work rest schedule), and physiological response to hot environments, it was observed that older men (39–45) equal the performance of younger men (19–31) in hot saturated environments (29 4–37 8°C, 85 100°F) (30) In a second experiment (17), it was found that the older men sustained higher pulse rates, forearm blood flows, rectal temperatures, and skin temperatures in the heat than their younger counterparts Although both age groups exhibited the same total sweat response to the heat work exposure, the pattern of response was different The older men responded in a more "sluggish" fashion than the younger men The time to onset of sweating was delayed twice as long when exposed to heat and to heat plus work, sweat rates remained high in recovery after work A third study (16) indicated that the number of functioning thermal sweat glands was the same in another group of middle-aged (44 57) and younger (18–23) men, but that individual glands were inactive longer in the older group when exposed to heat Thus

for the sweating mechanism to respond to the combination of environmental conditions plus exercise Since the above studies did not involve acclimatized subjects, the rapidity of acclimatization by the middle aged remains an interesting problem In addition, the environments used did not exceed 37 8°C (100°F) When exposed to extremely hot conditions of dry bulb 40°C plus (104°F+), where the rapidity of the sweating mechanism becomes crucial in terms of tolerance, the middle aged presumably would be at a considerable disadvantage The latter point deserves further investigation

SEXUAL ACTIVITY

During middle age sexual "vigor' declines on the average, although considerable variation has been found from one household to another (25,26) While a well documented age trend in frequency of sexual outlet exists for both male and female, a relationship between habitual physical activity and/or past history of physical activity to the age trend has not been established

Although undocumented claims have been made for the beneficial effects of exercise in relation to sexual vigor and postponement of the climacteric, the limited evidence neither substantiates nor disproves these claims Nor is there evidence pertaining to either a general or specific type of physical fitness which would facilitate tolerance of the "strain" of the sexual act The adverse social implications attached to the conduct of controlled laboratory experimentation have largely stymied research efforts Most clinicians, particularly those interested in the area of chronic cardiovascular disease, are

acutely aware of the possible hazards of sexual intercourse in their patient populations, but even this awareness has not been sufficient to overcome imaginary and real obstacles confronting the would be investigator

Caloric and Nutritional Problems

One of the important problems currently associated with middle age is obesity Although the etiology of obesity is complex, it is related in part to the excess dietary habits of the middle age group in relation to decreased energy expenditure The lessened daily energy expenditure in the middle years as compared to the teens and twenties is brought about in two ways (1) reduced basal energy expenditure, and (2) reduced energy expenditure associated with physical activity, *i e*, not as much physical work is performed per day Appetite does not appear to be regulated as precisely during the middle years as it is during growth period with the result that large changes in body composition take place from youth through middle age Usually body fat increases and fat free body weight decreases while gross body weight may increase slightly or not change (23) The gain in body fatness from age 25 to age 55 is approximately 10 percent of the gross body weight (5)

If habitual exercise is undertaken through the years, the age trend of developing obesity may be modified A survey of the effect of habitual participation in recreational activities was made by comparing subsamples from a group of healthy middle aged business and professional men (5) One subsample was comprised of so called 'active' men (n 29) and the other of "inactive" (n 27) or relatively sedentary men The two groups were matched for age (52 2 and 52 9 years) and height (176 1 and 176 2 cm) It was found that the "active" men were heavier (81 5 vs 78 3 kg), possessed heavier fat free body weights (64 0 vs 59 7 kg) and had lower percentage body fat (21 5 vs 23 8 percent) The active men were also appraised as having "little of the disuse atrophy characteristic of 'normal' aging"

While the [illegible]

ing body fatness with age, does so at a slower rate than the sedentary person Th [illegible]

weight, voluntarily "watch" his diet? [illegible]

[illegible]

nor comprehensive, is convincing and deserves thorough consideration Or

particular significance is the fact that weight gains frequently accompany sedentary living Mayer believes that a distinct activity level exists beyond which body weight remains constant (caloric intake parallels energy expenditure), and below which weight gain ensues (caloric intake exceeds energy expenditure 32)

Exercise in Relation to Cardiovascular Disease

The concept that physical exercise may be a protective factor safeguarding the middle-aged from the ravages of cardiovascular disease is not new, however, most investigations of this problem were initiated only recently The results to date are interesting but not conclusive In England, the incidence and severity of coronary heart disease was compared in two employee populations, transportation and postal workers (34) Both groups were separated into subgroups on the basis of the amount of physical activity essential to their job In the transportation industry, conductors who took tickets and performed other chores on double decker buses were compared to the more sedentary drivers In the postal group, the walking delivery postal carriers were compared to the office workers The physically active subgroups in both transportation and postal operations had relatively less coronary heart disease and the heart disease they did have was less severe Although the incidence of angina pectoris (or labeled thus) was higher in the more active men, this was associated with their higher incidence of nonfatal cases

Another study is currently underway at the Laboratory of Physiological Hygiene, University of Minnesota (40) Medical history and physiological function in railroad workers is being evaluated (150 railroad clerks were classified as sedentary and 150 switchmen who work outdoors in the railroad yards were classified as active) In preliminary electrocardiographic tests performed before and after treadmill work, the incidence of abnormalities was significantly lower in the switchmen than the clerks Care was taken to eliminate all men with arterial hypertension

In these two studies, exclusive reference was made to a possible relationship of exercise to the development of cardiovascular disease The authors are well aware of other factors such as diet, dietary composition, self selection of jobs, genetic background, etc, that may contribute to the etiology of heart disease Quite frequently factors such as diet and activity are intimately related, with one mutually dependent on the other, so that clear separation of causation becomes a complex task

Attempts have been made to separate 'effects' attributable to diet and physical activity on levels of serum constituents commonly 'associated with atherogenesis, i e, cholesterol and beta lipoprotein In acute exercise experiments, both a slight reduction and no change in serum cholesterol has been found (31,45) In populations where chronic physical activity has been investigated, the conclusion has been drawn that diet and particularly

fat content has more influence than physical activity on both serum cholesterol and beta lipoprotein levels (22,24) Only the groundwork has been prepared in this important area of investigation The next few years should yield important contributions to ease victimization of the middle aged by cardiovascular disease

CONFLICTING VIEWS—EXERCISE FOR THE MIDDLE AGED

Popular periodicals abound with articles which run the gamut from the opinion that the aging process can be decelerated by a rigorous program of exercise to one which advises that even moderate exercise may be detrimental to good health The first group theorizes that exercise increases life expectancy, extends sexual potency, "purifies the blood," etc, while Chauncey DePew's oft quoted claim that he, who lived to be 93, "got his only exercise by acting as pallbearer for his friends who took exercise," is a classic example of the latter group's philosophy

The question—why do people exercise in middle age?—has also received

crohn (42) believes that the force of self-destruction is the motivator which makes the middle aged person exercise He states "Exercise is a state of mind Like sheep we follow the leader We have been told that 'exercise is good for you', we have accepted this dictum without reason, and have subjected creaking joints and protesting muscles to unnecessary strain simply because we think exercise is a necessary adjunct to proper living Remember *you don't have to exercise*"

"average" middle aged person is not easily answered It would seem that

middle aged persons may profitably engage in most recreational activities, provided that the intensity and duration of the activity is realistically adjusted to their physical condition at the time This statement implies individual knowledge of "middle age" physical condition, and not a wishful appraisal carried over from the days of past athletic feats Under competitive conditions, such as a game situation, it is easy for the middle aged person to overlook the symptoms of fatigue and discomfort in order to emulate his victories of former days

Exercise has frequently been prescribed in the rehabilitation of some cardiac patients Certain cardiac cases have been encouraged to exercise as long as they proceed at a leisurely pace and conscientiously report deleterious effects of exertion to their physicians (29) Others also recommend progressive exercise for restoring the heart patient to an active life Walking, golf, shooting, swimming, and doubles tennis have been mentioned as possible activities

It has been recognized that recreational activities such as sports, hobbies, and games meet an important psychological need for the middle aged Proper use of leisure time in the middle age period prevents boredom Boredom hastens senescence by undermining morale and dampening enthusiasm Proper recreational habits may do much to make life more meaningful

The effect of sports activities upon the ego is described by Hambridge (15) His remarks may well provide a fitting conclusion to this chapter

The experience of the spectator is mild compared with that of the player, which is the reason games should be played, not watched from a grandstand At the risk of uttering a blasphemy I wish to remark that catching a fast ping pong ball and returning it with precision gives a pleasure not so far removed from that a painter feels when he makes a good stroke with his brush on canvas

And that is one of the reasons why athletic games are so valuable for those of middle age and beyond The game not only keeps the body supple and in "good tone"—which, after all, calisthenics would do, it subtly flatters the ego with a sense of mastering new and difficult things All of us need that kind of flattery *on occasion We get it in games* no matter how modest the skill required

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26 CELESTE ULRICH

Women and Sport

SUMMARY

Women's participation in sport is governed by certain biological, sociological, and philosophical concepts. The interpretation of these concepts depends upon the society and the time.

Biological sex differences influence the kinds of activities in which the majority of women can participate. Height, weight, organic structure, body type, circulation, respiration, metabolism, and endocrine secretion are all factors which may be influenced by the sex of the individual. These differential patterns in biology serve as an indication for the kinds of sport activities which will provide the greatest satisfactions for any one individual.

Some of the major differences between the sexes are found in the sociological customs insisted upon by any society. Because of the social mores maintained, psychic differences between the sexes result and may be emphasized. These cultural and philosophical differences are at least as important as the biological differences, but they are not so easily identified.

It is certainly reasonable to suppose that women will continue to participate in sports, for the tradition is now well established and undoubtedly activity of this kind meets certain physical and psychological needs of women as well as men. It is likely that sexual differences—biological and cultural—will continue to determine the particular form that sports and other physical activity programs for women will take. The sport program for women in the American society will continue to be "feminine" as long as it is participated in, directed by, and needed by women. The standards of the culture and the biological structure of the participants will undoubtedly direct the future of women's sports.

Women's participation in sport has been governed by the circumstances of custom, prejudice, and excuse. Each of these have been a part of the cultural pattern of a society at a particular time and the bases of these circumstances have been biological, psychological, and philosophical in nature.

BRIEF HISTORY

Until the time of the Greeks there is little reference to any sort of organ ized athletic activities for women although the Code of Hammurabi does specify that all of the people shall participate in exercise Plato in setting up his ideal state suggested that men *and* women should have the same sort of gymnastic training It is known that in the Greek city state of Sparta women exercised in the squares under the supervision of women trainers

From the fall of Rome to the Renaissance the influence of asceticism and later that of scholasticism kept sport in the background These isms cou pled with the medieval concept of chivalry almost eliminated women s ac tivities from the sports picture

With the advent of the Renaissance women again began to participate in sport although the process of raising and rearing children remained their chief occupation The seventeenth-century ladies engaged in sports such as handball club ball archery and other activities becoming the gentler sex Still later the Turnverein movement sponsored by Jahn and the Ling Gym nastic movement included women in their organizational plans

game of basketball as played by women The committee published girls rules for basketball with special stress on standards safeguarding the health of the participants Articles on health examinations articles against the win at all-cost theory articles on the differences between the girls and boys game and a definite statement concerning an expression of opinion on the overemphasis of too strenuous competition for women were all a part of the committee s work

The original philosophy of the women s athletic committees was con cerned with both avoiding the pitfalls which had been demonstrated with the men s interscholastic programs and with keeping the game safe and feminine for the girls It is interesting to note that the cultural pattern of the society so dominated the thinking that there was much pseudobiological evidence presented regarding the differences between men and women

One of the most important topics concerned the menstrual cycle It was assumed that during menstruation women were to be shielded from any type of emotional or physical strain

In addition article after article appeared with scientific evidence,

claiming that women were naturally biologically inferior to men and hence might not be able to take part in any competitive sports situation, even if they wanted to do so

About the time of the 1920's really objective research work was done on sex differences There was a multitude of evidence to support the thesis that there are some differences which might be justifiably attributed to sex However, these differences once established, seemed to grow less important in subsequent studies of behavior and function It is these differences which affect the picture today with regard to women and sport and it is the understanding of these differences which fosters intelligent planning of sports for women

ANATOMICAL DIFFERENCES

Genetic The female embryo is created by the fusion of two X chromosome

the defective gene With the male embryo, where there is a defective gene in the X chromosome, there is no matching gene and this may determine a defective characteristic in the embryo which may result in abortion miscarriage or genetic imperfection

Skeletal The skeletal differences between men and women begin at birth By the 18th–20th week certain ossification begins in the female skeleton (36) and such bones as the pisiform and the epiphysis of the metacarpals

be explained partially by the fact that the muscles of the male are heavier and hence the pull on the bones is greater causing heavier and more massive bone development (8 16)

There is some indication that the male has a more prominent nose, higher cheekbones a squarer, heavier jaw, heavier ends of the long bones, and deeper grooves where the muscles attach (36) The angle of the female arm may be different from that of the male in that the female arm often conforms to the angle made along her side by her narrow shoulders and protruding hips

The shoulder width of the female is narrower than that of the male, while the female s bony pelvis is relatively shallower and broader than the male s The female pelvic girdle often appears grossly broader than the male s because of the adipose pads formed over the hips This surplus of adipose

tissue, plus the narrower shoulder, tends to emphasize and exaggerate the hip width in women However, there is great diversity within both sexes with regard to hip and shoulder width and it is difficult, if not impossible, to make a sweeping generalization about these characteristics in either the male or the female

Growth The growth pattern for the female is more accelerated than that for the male and most girls achieve their most rapid growth spurt 2 24 years before boys (38) Except during the prepubertal period, the male has a slight advantage in height which he maintains into adulthood (7) The mean height of the adult female is five to six inches shorter than that of the adult male

The adult male is about 20–25 percent heavier than the female The excessive accumulation of fat in the female, and the development of the bust explains, to some extent, the proportionally greater weight of the female It is reported by Moore (27) that the average adult female has about seven more pounds of subcutaneous fat than the average man

In general, the male growth period extends over a longer expanse of time than that of the female, and because of his longer growth period, the male between the age of 12–17 has greater proportional growth in height, weight, breathing capacity, sitting height, and chest girth (2)

In relation to height, the chest girth of the male is greater than the females, and hence the male's thoracic region is larger Conversely, the abdominal cavity of the adult female may be larger than that of the male

Cotton (13) found that the mean center of gravity in the female is approximately 0 6 percent lower than that of the male This differential is brought about mainly by the man's greater height, broader shoulder width, and narrower hips

The lower leg in the female may be shorter than that of the male and often the height of the male is found in his leg length The average male foot is of greater length and width than the foot of the female, and the man's arm length generally surpasses that of the women

There seem to be many indications that, while the female's maturation pattern is accelerated when compared to the male's, the longer growing period for the male produces a heavier, more massive individual with relative structural advantages, especially in the upper body development

FUNCTIONAL DIFFERENCES

The structural composition of any individual governs his functional patterning, consequently, when the possibility of gross structural sex differences is recognized, the possible effects of these structural differences upon function should be taken into account

Circulatory The larger heart of the male may be the result of his larger proportion of muscle tissue which requires better circulation than the con

trasting proportion of adipose tissue in the female This heart size differential causes a faster heart rate in women (44) The average red blood corpuscle count in the male is 5 000 000 per cubic millimeter as compared with 4 500 000 in the female The blood of the male has about 8 percent more hemoglobin (17) and the specific gravity of the man's blood is higher than that of the woman The systolic and diastolic pressures are generally about 5-10 mm higher in the male

Respiratory The smaller thoracic cavity with the smaller lungs tend to increase respiratory acceleration in the female (17) In the woman the movement of the upper part of the chest is conspicuous during respiration (the chest appears to rise and fall with every respiration) while the male's respiratory movements are often entirely confined to the lower part of the chest with the diaphragm being the chief respiratory agent Apparently, since less oxygen is needed by the female because of her smaller size and lower metabolic rate, her breathing capacity is lower

Metabolic The female metabolic rate is lower than the male s at all ages (3 4,16) This metabolic rate varies somewhat during the periodic sexual cycle and it is believed that the metabolic rate influences the respiration

calcium metabolic rate (34) than in the male, while the larger and more massive bones of the male indicate that there is a greater retention of calcium in the male during growth The female s calcium metabolic rate ap-

time is quicker in boys from 6–17 years of age but there is no indication that this speed persists in adulthood

this gland regulates metabolism there would appear to be a key sex linked characteristic inherent in the thyroid gland The pituitary gland is usually

larger in the female (27) There seems to be no basis for assuming that the endocrine secretions are different in proportional quantity or quality between the sexes and there is much reason to assume that the results of similar specific endocrine secretions are the same in both sexes

Probably one of the most discussed sex differences is the menstrual cycle of the female Medical opinion suggests that the female should refrain from strenuous activity involving intense competition during the first two days of her menstrual period Mild exercise, on the other hand, may be very beneficial in ameliorating congestion which is often the cause of menstrual discomfort

Although dysmenorrhea may be due to inadequacy of abdominal strength and in some cases may be corrected by certain exercises, there are often psychic factors involved Dysmenorrhea does not appear to alter body reactions significantly except insofar as inability to function results from pain It is obviously not desirable for susceptible females to participate in any activities which cause increased abdominal pressure on the pelvic floor during the

... situation

Naturally, in the pregnant female there are many body changes, both structural and functional, which tend to affect her activity pattern

PSYCHOSOCIAL DIFFERENCES

At the present time nothing definite can be said regarding the "real" psychological differences between the male and the female, and in most cases in which such differences have been claimed, it has been evident that social factors rather than actual sex factors are accountable

In the current American society certain psychological attributes such as intuition, endurance of stress, and vacillation tend to be associated with the female, while attributes such as thinking logically, tenacity, and being relatively free of domination by emotions are associated with the male

In the same vein, but adding the dimension of cultural change, lingering tradition maintains that the female is protected, restricted, and submissive, but on the other hand, in terms of popular thought, the "modern" woman is adventurous, unrestrained, competitive, and aggressive

The ambiguities of sex role in a changing culture are, of course, reflected in the American sports picture Until after 1900 it was not considered proper that college girls should participate in vigorous, competitive sports Such behavior was considered "masculine" More recently outstanding women athletes could expect to have their essential femininity questioned because

their sports performance was not entirely in line with the cultural prescription for their sex

The association of athletics and masculinity in the American culture poses a rather interesting and complex problem for the sports minded girl If to be successful, the boy is to "play like a man," that is, to be confident, brave and harde

like?

of "tc

is assumed, will be outgrown as femininity asserts itself This dichotomy of concepts regarding women and sport perpetrates confusion in the minds of

the role of girls and women in this society

CONCLUSION

The evidence indicates that although the anatomical and functional differences between the sexes are not so radical as were once thought, there are some biological generalizations about the "average" individual, with regard to sex, which may be used as indices for sports

Sports, where the outcome is largely dependent upon strength, endurance, and power give the male an easy advantage Therefore, unless women compete against women, a disproportionate contest results Furthermore, the biological generalizations regarding "average" sexual differences support the theory that in order to have challenging and equal corecreational acti

climate of the time As such they are difficult to define

It is essential that all sexual differences be interpreted in their correct frame of reference Biological differences should not have a psychosocial interpretation nor should psychosocial differences be attributed to biology

Although the 'average' person is considered when comparing sex differences, in sports it is difficult to deal with an "average" person either biologically or behaviorally It is so decidedly *an* individual who meets any given situation and any one individual may represent the extreme as well as the

Women will doubtless continue to participate in sports, for activity of this

kind meets certain physical and psychological needs It is likely that known —and as yet unknown—biological and culturally derived differences will determine the particular form that sports and other physical activity programs for women will take

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27 HENRY J MONTOYE

Sports and Length of Life

SUMMARY

Attempts to study the effects of sports participation on length of life have been, in the main comparisons of the longevity of college athletes (letter winners) with insurance mortality tables based upon the general population However, two comprehensive studies and two of more limited scope in which comparisons were with the college classmates of the letter winners and not with the general insurance risk indicated little difference in longevity of the two groups There is appreciable evidence that former college letter winners die more frequently of violent deaths (accidents, suicides, homicides, and war deaths) than do other college graduates

A pilot study taking into account a variety of factors indicates that although there appear to be rather distinct differences between athletes as a group and nonathlete controls both as to physical capacity and other characteristics while in college, by middle age or before, these differences are not nearly so marked Apparently few training habits carry over into later life Mode of life and amount of physical activity at various periods of life rather than sports participation in youth may well be the important question in relation to longevity

Since very early times, men have pondered over the effects of strenuous exercise and athletics *Hippocrates and Galen believed the consequence of competition in the sports arena was an early death (11) This view prevailed* into the mid nineteenth century when in 1873 Dr John E Morgan, an English physician of distinction and former oarsman, compared the longevity of athletes with the general population (17) His investigation revealed that men who rowed in the Oxford Cambridge boat races between 1829 and 1869 lived about two years longer than the 'average' Englishman as expressed by insurance tables

There followed a series of similar studies by Meylan (14), Anderson (1), Hill (12), Dublin (8), Cooper, O Sullivan, and Hughes (4), Knoll (13),

to insured populations is unjustified considering the selectivity implied in attendance at college, particularly in these early years There is appreciable evidence that college graduates regardless of participation in athletics live longer than the average insurance risk (8,217) This is no doubt due to the medical, nutritional, and occupational advantages associated with university life and with the socioeconomic positions of graduates Many of the graduates of universities during the periods of these early investigations entered the clergy and other professions These occupations have been known for a favorable life expectancy (8,214) The heredity endowments of college graduates may also be advantageous

In the most important studies reported in the literature the criticism discussed above was avoided by comparing letter winners (athletes) with their classmates Greenway and Hiscock found the life expectancy of Yale athletes to be greater than standard life insurance risks, but slightly less than

to the fact that they were a part of a larger select group, namely college graduates, since there was little difference in mortality between general college graduates and athletes in the second investigation The small difference in life expectancy (0 25 years on the average) was in favor of the general graduates The greatest difference in life expectancy (0 6 years) occurred at about 50 years of age At almost every age, however, 6500 scholastic honor men had a life expectancy of 1½ to 2 years greater than the general graduates

Reed and Love compared the longevity of former letter winners at West

of the mortality of athletes with their classmates (20) There were 834 athletes, 379 nonathlete controls, and 382 academic honor winners, all graduates of Cambridge University The athletes lived on the average 0 5 years longer than the nonathlete controls whereas the "intellectual group" lived

on the average 2 years longer than the controls Sir Allen Rook went a step [illegible] years longer than the heavy athletes

The similarity in the studies by Dublin and Rook with respect to the mortality of academic honor winners deserves comment The lower mortality of the honor man can hardly be explained by military deferment or military billet since war deaths were excluded in Rook's study Intelligence and good judgment may have been significant factors together, one might guess, with a more favorable heredity It is entirely possible, too, that the honor winners may have entered occupations less hazardous than the general graduates

Recently another study (16) produced results very similar to those of Dublin and Rook with regard to the longevity of letter winners Of 628 college athletes and 563 nonathlete classmate controls for which information was available, there were 67 deaths in the former group and 56 in the latter The difference in life expectancy of the two groups was less than 0 4 years in favor of the nonathlete controls

Also of interest is the closely allied question "Is there a difference in the causes of death of athletes as compared to nonathletes?" Limited investigations bearing upon this problem have also appeared in the literature but again, there is a paucity of well controlled research Meylan (14), Anderson (2), Greenway and Hiscock (10), Dublin (5), Bickert (3), Knoll (13), and Van Mervinne (22) reported distributions of causes of death among their athletic subjects However, adequate control data on nonathlete subjects were not reported

In 1944 Wakefield compared the causes of death among 2919 former high school athletes who played in the Indiana State basketball tournament with causes of death in the general population of Indiana (23) He found about the same percentage of deaths due to pneumonia and influenza among the athletes as in the general population but fewer deaths due to tuberculosis (13 8 percent among athletes compared to 20 9 percent) and slightly more cardiovascular renal deaths among the athletes (16 3 percent versus 13 3 percent) The biggest difference, however, was in the violent deaths which were considerably more common among the athletes (34 0 percent versus 17 3 percent) Several previous investigators had reported high incidence of violent deaths among former athletes (Meylan, 1904, Greenway and Hiscock, 1926, and Knoll, 1938) Wakefield's study may justifiably be criticized on the basis that the general population of the state of Indiana hardly represents suitable controls

Rook and Montoye, *et al* compared the distributions of causes of death among former athletes with those of their college classmates (20,16) In addition, Rook had a group of academic honor winners who were also class mates of the athletes and controls Rook found little difference in deaths

due to cancer, influenza, pneumonia, and bronchitis in the three groups There were slightly less heart, vascular, and renal deaths among the former athletes (41 6 percent), than among the random controls (48 6 percent) or the intellectual group (48 1 percent) In Rook's study there were also more violent deaths among the former athletes (11 6 percent) than the other two groups (7 0 and 8 8 percent respectively) even though war deaths were excluded The numbers of cases in his study were as follows athletes, 439, random control, 142, intellectual, 172

Although the second report (16) included only 123 deaths in which the cause was known, the results are similar to those of Rook The difference in distributions for causes of death was not statistically important for the former athletes and their classmate controls Verification of the cause of death in the majority of cases was possible through the examination of photostatic copies of the attending physician's report The causes of deaths reported by relatives of the deceased were found to be highly reliable when compared to the medical opinion rendered by the physician at the time of death There were less than 2 percent gross errors

It appears quite clear that there is little difference in the over all life expectancy of college letter winners and the average college graduate However, academic honor winners can expect to live a year or two longer There is appreciable evidence that the probability of a violent death is greater for college athletes than for their nonathlete classmates These men may be more adventurous and perhaps may eventually be employed in more hazardous occupations

An extensive study of many factors which bear upon the longevity and morbidity of former college athletes is under way These include medical history (ailments, weight gain since graduation from college, childhood diseases, etc), family history (longevity and causes of death among grandparents, parents, and siblings) military service, physical activity at various age periods in life, smoking and drinking habits, etc An analysis of these factors for 628 athletes and 563 controls has been reported recently (16) From this pilot study several significant conclusions have emerged Although there appear to be rather distinct differences between athletes as a group and nonathlete controls both as to physical capacity and other characteristics while in college, by middle age or before these differences are not nearly so marked Even in college there appears to be greater differences among athletes in different sports than between athletes as a group and classmates who did not earn varsity letters It appears that few of the training habits, that is, vigorous exercise, abstinence from the use of tobacco and alcohol, etc , carry over into later life It will no doubt be more fruitful to compare those [illegible] with

[illegible]

and competition apparently are transient qualities. It is more likely that the

importance of exercise in daily living will become apparent when men who remain relatively active throughout their lives are compared with those who remain relatively sedentary

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PART IV

Psychological Aspects of Exercise and Sports

20 Rook, A An investigation into the longevity of Cambridge sportsmen *Brit med J*, 1954, 1, 773–777
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28

CHARLES N COFER AND
WARREN R JOHNSON

Personality Dynamics in Relation to Exercise and Sports

SUMMARY

This chapter is composed of three parts (1) an overview of four major modern theories of motivation with their respective implications for why people exercise, play, and engage in sports, (2) a discussion of personality testing and personality tests, and (3) a review of personality studies that have been done in relation to sports, a discussion of changes in motivation to play and compete in sports during the course of maturing and aging, and a note on hypnotic research in this area[1]

Part I—Theories of motivation Four theories of motivation are described those represented by Freud, Hull, Hebb and Maslow (1) According to Freud, human motivation is explicable mainly on the basis of unconscious forces related to libido, their manifestations in the Oedipus situation, and in compensatory behavior undertaken to resolve conflicts (2) According to Hull and his associates, motivation is built on primary drives through learning on the basis of the law of effect Drive is seen mainly as an energy factor in behavior rather than as a steering gear determining what the person will do (3) According to Hebb and his associates, human motivation derives from basic needs to be curious, to explore, to manipulate, and to solve problems (4) According to Maslow and his associates, although 'deficit' motivations, such as those of (1) and (2) above, are needed to explain much

sulted for information relative to both chapters

human behavior, when basic needs for such things as safety, comfort, and respect are granted or achieved, it is possible for human beings to operate on a "self-actualizing" level At this level, people do not strive in one area, e g, sports, to compensate for inadequacies, tensions, or aggressions in another area, but engage in activities as ends in themselves rather than as means to other ends

Part II—Measurement of personality and motivational variables In this part, problems of reliability and validity of personality testing are discussed, various types of measurement procedures are presented and their limitations noted, and pertinent references related to personality measurement are cited

Part III—Personality studies related to exercise and sports Efforts have been made to determine (1) whether there are differences in personality among various types of athletes, (2) whether outstanding performers have distinguishing personality traits, and (3) whether participation in or observation of play or sports gives rise to changes in personality dynamics

A number of studies indicate that certain types of athletes and activity groups have identifying personality characteristics, although no light has been shed upon the extent to which sports participation has been a factor in bringing about lasting changes in personality traits

Some investigations suggest that champion athletes have distinguishing personality traits

A few studies have been designed to determine the immediate and/or seasonal effects of sports competition upon personality dynamics Indications are that the anticipation of some types of sports competition is associated with rather severe, temporary psychological reactions Research reported lends support both to the theory that aggressive tendencies are diminished by overt aggressive behavior (cathartic theory), and to the theory that aggressive tendencies are increased by overt aggressive behavior (circular theory)

One investigator reported evidence that moderate weight loss associated with high school wrestling gives rise to a reduction in aggressive tendencies, another, on the basis of a pilot study, reported no evidence in support of the theory that strenuous exercise and/or competition lowers sexual tension, and still another reported changes in the personality dynamics of spectators after watching a series of boxing matches

A pattern of change in the psychological significance of play, exercise, and sports as transition is made from childhood to adulthood is proposed It is suggested that motivation to play and compete in sports undergoes change at the different levels of the maturing and aging process, and that at some levels motivation is more of the "driven" and compensatory kind (some stages of childhood and later adolescence), but that at others it is more of the unmotivated (preadolescence) and perhaps, though rarely, even self actualizing kind (mature adulthood) Wrestling may be used to illustrate how the meaning of a sport can undergo change in the span between child

hood and adulthood, in that at some stages it is a means to an end, while at others it is an end in itself Changes in motivational tendencies, and the meaning of play and sports at different periods of life have important implications for physical education curricula and methods

Hypnosis has been studied to some extent in an effort to determine its effects upon physical performance, it has been used as a means to investigate underlying and unconscious motivation to play and compete in sports, and posthypnotic amnesia has been used as a means of controlling the psychological variable in exercise studies

THEORIES OF MOTIVATION

To speak of motivation and the nature of personality in a book concerned with exercise and sports requires some introductory conceptualization of possible relationships of these topics to the subjects of this volume Let us begin by raising certain questions which can indicate the kinds of relationships that may be involved First, we may ask, why do people engage in exercise and sports? Are there motives or needs whose direct expression lies in these activities and whose force is present even though other motives and needs are lacking? Such questions might be answered affirmatively and then the further query would concern the description, origin and nature of such motives But it is also possible to suggest that there are no motives or needs which lead men to exercise and to sport, yet people engage in these activities and the question remains, why? A second answer or hypothesis could be that motives, whose direct expression or gratification lies in other activities, can nevertheless underlie and perhaps be gratified in whole or part by exercise and sport This answer implies a much more complex and indirect relationship than does the first There is of course a third hypothesis—that there is no relationship between these motive factors and the activities with which we are concerned

Recent work has concerned the role of motivational and personality variables in exercise and sport, and it seems to be predicated upon the second of the foregoing hypotheses concerning the relationship, both with respect to the performer and the spectator Further some investigations have sought in motivational and personality factors the bases for exceptionally able performance, as in champion athletes These several areas will be reviewed in a later part of this chapter In preparation for this review there follow discus

CONCEPTIONS OF MOTIVATION IN RELATION TO PERSONALITY

It is probably a fair generalization that most of the current conceptions of the nature of personality (2) agree in viewing personality as an organiza

tion of enduring and characteristic ways of perceiving, feeling, and acting which have arisen in the service of motives This is to say that personality is regarded as a stable product of the interactions of the motivated individual with his environment and that the manifestations which we call personality are highly developed means by which the individual, consciously or unconsciously, copes with the motivations which have impelled or do impel him in his dealings with his social environment, that is, his interpersonal relations Such a conception makes of motivation the primary concept and of personality an expression of motivations, by reading the expressions of personality we may be able to understand the underlying motivations This is what is ordinarily meant by a dynamic conception of personality

It should be pointed out, however, that this is not the only conception which is possible One may simply attempt to describe the individual in terms which indicate his major characteristics and raise no questions concerning the origins of these traits in motivational terms There is value in this position, but we shall not further concern ourselves with it here, referring the reader, however, to several sources where it is described (41,76,2,18)

The formulation of the dynamic conception of personality suggested above describes it at a highly general level, but there are many variations in the details which different theorists have advanced We can give here but a few representative illustrations, which, in the writers' opinions, indicate dominant and developing conceptions On present evidence, it is not possible to choose among them, but they all significantly guide research and even practice in many areas of the social and behavioral sciences

We may begin broadly by suggesting at once that the viewpoints to be described divide themselves into two camps, based on the number of basic or primary motives they postulate Likewise they differ in the extent to which drive or tension reduction seems to be advanced as the prime goal of or as the prime basis for the control of action The first two sets of theories agree in postulating a few basic motives and in emphasizing tension reduction, the next two classes seem to employ multiple motive states and to avoid commitment to an exclusive tension reduction principle These four classes are outlined below, and the descriptions have been slanted so as to bear on the problems with which this chapter began.

In passing, it should be observed that constitutional theories of personality and motivation do not as such play a significant role in the current scene None of the four classes outlined below would deny constitutional or hereditary processes in motivation and personality, but none seems to make a major and practical variable of them For the one current viewpoint which is heavily constitutional in its emphasis, see Sheldon (99,41).

Motivation as a Central Concept, with a Purposive Function

In the older instinct theories, such as that formulated by William McDougall (73), the instinct was seen as the prime mover of conduct More

than this, however, was involved because conduct was seen to *strive toward* the attainment of those goals necessary to instinct satisfaction We could almost say, then, that the instinctive urge contained some indication of the actions or objects appropriate to its expression

While instinct theories of grand scope like McDougall's are no longer taken very seriously, nevertheless the primacy with which his view endowed the motivation construct as a factor in behavior and, to some extent, the purposive, intentional, selective, or directive function of the motive are prominent features of one large class of motivation personality theory today It would seem that there is much in common, for example, between Mc Dougall and Freud in these respects, and Murray (87) has explicitly indicated his debt to McDougall (as well as to Freud) in writing of his own personality theory It seems fair to assert that Freud s theories and theories which closely resemble his are dominant today in psychiatry clinical psychology, and related fields and that they have a powerful influence over the whole range of the behavioral and social sciences They fit in, too, with a commonly expressed layman's belief that the answer to the question "Why?" in matters of human behavior is a motivational one

We shall here attempt a summary of some of the salient features and assumptions of Freudian psychoanalytic personality theory, reserving to a *later discussion the description of certain viewpoints which while partially* derivative from Freud yet deviate from his views significantly No effort will here be made to discuss psychotherapy, as this topic, though a major aspect of psychoanalysis, is not relevant to our present interest[1] Adequate summaries both as to Freud s views and as to psychoanalytic therapy may be found in Freud (32,33), Blum (13,), Thompson (104), Mullahy (85), Hall (40), Munro (86), Hall and Lindzey (41), Fenichel (27), Fromm Reichman (35), and Hendricks (46)

Freud postulated but two basic instinctual forces, those having to do with life processes (Eros) as represented by the sexual instinct and its energy, libido, and those having to do with death, aggression, and destruction Many writers have rejected the death aggression instinct, arguing that an al

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, if ever, seen in a pure form

but usually appeared in fusions with some aspect of Eros, as in sadism and masochism It makes a considerable practical as well as theoretical difference if one does or does not assume or demonstrate such an instinct, and perhaps the majority of current writers would not postulate it

The sexual instinct was thought to arise virtually at birth and to pass through a number of manifestations before it reached or could reach mature

[1] The chapters by Emma Layman Physical Activity as a Psychiatric Adjunct' and 'Contributions of Exercise and Sports to Mental Health and Social Adjustment,' contain information that is relevant to this general subject

expression in adulthood These earlier periods of sexuality, correlated in time with the preschool and kindergarten ages, were known as periods of infantile or pregenital sexuality Every person, according to this theory, passes through these stages first the oral, then the anal, and last the phallic (or early genital) periods, when maximum pleasure, seen as gratification from the stimulation of these bodily regions, is gained successively in these zones Correlated with the use of these bodily zones for pleasure was thought to be an egocentric and narcissistic view of the self in relation to other people, such that others were primarily related to in terms which would permit the youngster s satisfactions without concern for the welfare of the others The child was conceived as a primitive, egocentric being, largely motivated to his own pleasure (defined as reduction of libinal tension) and mentally unable to think very logically or rationally The Oedipus Complex and the Castra tion Complex, well known Freudian notions are thought to rise in the latter portion of this pregenital or infantile period

As indicated above, according to psychoanalytic theory all people are be lieved to pass through these periods, although some lasting effects from each such stage would persist in any case But relatively few people do so suc cessfully, that is, without some difficulty, and Freud thought these difficulties lead to fixations which may be defined here as the lasting attachment of some amount of the libido to some zone or zones or stage or stages of de velopment In explaining such fixations Freud called both on constitution and on experience In some people, he suggested, for constitutional reasons a given zone is very readily fixated in others, experience determines the fixa tion Thus a child too quickly weaned might retain some fixation at the oral level another might so remain also, but because of excessive satisfaction in the sucking experience While Freud always insisted on the possible in volvement of constitution in fixation later writers (104) have stressed experi ence

As we have said, the child (and the adult too) seeks pleasure (domination by the pleasure principle), defined as reduction of libinal tension, through gratification of a drive or instinct But for various reasons, every child experi ences frustrations, even when he has the most solicitous and watchful parents More typically his parents reject the kinds of satisfactions which the child seeks, even to the point of dire threats, for example, when they observe him in masturbation And so the pleasure seeking child, forced to face frus tration, threats, and punishments and desirous of minimizing these factors must live, as well, according to the Reality Principle This situation would encourage the development of a fixation, probably through the frustration of the libidinal urges, and the personality might become organized around such

of the opposition of the pleasure principle, as represented by the Id, which

contains the instincts and functions according to the pleasure principle, to the reality principle, represented in the Ego Control over the Id was vested in the Ego, but the latter agency, in Freud s conception, had a difficult role In the first place, the Id s interests were dynamic forces whose urgency was increased, not abated, by frustrations, some degree of satisfaction must be accorded them In the second place, the Ego must perceive and take into account the demands and restrictions of external reality which might be expected to react to the unbridled expression of id impulses with hostility, punishment, and rejection Third and more important than the second, was the Super Ego, to which the Ego also was subject This agency was created in the image of the person s parents and it functioned to prohibit actions or to encourage others which fell respectively within its disapproval or its approval (Ego Ideal) The Super Ego had a great capacity, as had the parents before it, to arouse guilt, shame anxiety and feelings of self esteem or their reverse in the Ego, and the Ego was seen to respond abjectly to this master

Freud's observations led him to believe that the Ego could use a number of techniques, or defense mechanisms, in its troubled role of giving the Id

tire energy from the Id, whose impulses, chiefly the sexual ones, may therefore be said to underlie most, if not all, of a person s behavior An individual s major achievements—knowledge, institutions, arts and the like, as well as deficiencies and failures—were attributed to the same instinct sources often variously transformed and disguised by the Ego in order to by pass the Super Ego It should be clear that most of these actions, events and agencies were seen as operating unconsciously, Freud thought that what we are aware of or can become aware of represents but a very small portion of our mental lives And most of this unconscious material never becomes conscious, short

Representative of them are repression, projection, reaction formation identification, sublimation In all of them the instinctive energy is displaced, that is, it is directed to actions and objects other than the object or action of choice Some mechanisms are thought to be more effective than others Sublimation, *for example being the channeling of instinctual energy into socially* approved activities, relieves the underlying instinctual tension, the mature man would use this mechanism over others But repression, for example, denies any expression to the instinct

We may return to the original questions of this chapter It seems unlikely that in classical psychoanalysis exercise and sport would reflect the direct expression of motives for those activities Rather they would probably receive their impetus from other sources, say pregenital drives, or express de

fensive operations of the Ego Children's play, for example, was seen as a way of overcoming anxiety and obtaining mastery of many fears by experiencing a threatening situation over and over again in games It is often argued that vigorous exercise may be a way of discharging aggression, arising from other sources Or the display of one's body in scanty attire, the realization that one's muscles are bigger than someone else's, or winning in a contest over some adversary may all serve some narcissistic, pregenital impulse One's attitudes toward his parents or his siblings might also be involved in any activity in this area It is difficult to generalize, however, even to the assertion that interpretations like the foregoing are plausible, except in individual cases Freud worked primarily with neurotics, in whom he readily found evidence for the motivation of the most widely differing activities by the same sources That his interpretations have not been entirely convincing, even to all psychoanalysts, may be seen in a later sect [illegible] ent, he obviously attached great import[illegible] apparently derived [illegible] udy [illegible] (93)

[illegible] CONCEPT, WITH ENERGIZING AND [illegible] FUNCTIONS

Theories of the previous class look on motivation not only as the factor that explains why there is any behavior at all but also as a major, or perhaps the main, factor which accounts for the specific acts that occur, specific acts are selected in the light of motivational goals, and behavior is regarded as purposive intentional, directed, or guided as a direct or indirect outgrowth of the active motive itself In the viewpoints of the present class motivation serves a somewhat different function motivation arouses behavior tendencies to action in the presence of appropriate stimuli and it serves as a basis for reward and therefore of the learning of behavior tendencies, like habits But the direction, purpose, or intent seen in behavior is ascribed here to the controlling factor of habit, which is not, by definition, a motivational term An analogy, similar to one employed by Woodworth (116) many years ago, may clarify this point An automobile, with its engine at rest, contains all the structures necessary for locomotion, and, with a driver at the wheel to steer, its locomotion is directed But only when its mechanisms are activated by an energy source, as by the explosion of gasoline vapor in its combustion chambers, will the machine go anywhere It is important to note that all the energy source does here is to activate the mechanisms, they, together with the driver, impart the specific properties of the motion, including its direction (or misdirection) Woodworth equated motivation (or drive) to the energy which makes the machine go But it is an energy which activates only, it does not steer or lead the machine to any special place

This conception of motivation is well represented in the formulations of

Hull (52) and of his associates and followers, Dollard and Miller (22), Brown (15), Farber (25), Irwin (54), Hall and Lindzey (41) Hull (52) conceived motivation as a factor essential to the appearance of behavior and as a factor involved in the vigor with which it occurs He suggested that the role of motivation is to energize or to sensitize the neural structures which underlie habits or which underlie innate behavior patterns, specifically he argued that the strength of motivation is to be multiplied by the strength of the learned or unlearned connection, and the resultant value will, other things being equal, indicate the potentiality and strength of the behavior It is noteworthy that motivation here does not steer or direct, it only activates or sensitizes the learned or innate structures which give direction Any drive, like hunger, thirst, or fear, present in the organism would energize any or all habit structures, and which one would supervene would be the result of its habit strength as multiplied by the drive With each drive, of course there would be also a distinctive stimulus pattern, say stomach pangs for hunger or a dry mouth and throat for thirst These stimulus patterns have directive properties, but these are due to their roles as stimuli in habits, not to their energizing functions To repeat, in Hull s system drive simply energizes it never as such steers or directs, and it can be viewed as one of a number of coordinately primary concepts

The comment has already been made that motivation concepts here serve as a basis for reward, i e, as a central feature of the learning theory which is the best developed aspect of Hull s system Hull adopted a modified version of Thorndike s law of effect (105), Hull suggested that if a response occurs in approximate temporal contiguity to a stimulus and in the presence of the reduction in a need or drive, there would be an increment to the tendency for that response to occur in the presence of that stimulus, i e, habit strength is increased

In this system, then, motivation plays a central role in arousing habits to action and in the acquisition of habits, but the habits themselves, not the drives or motives, channel the behavior in this direction or that

other drives may arise through learning, and perhaps the major part of human motivation, from this view, would be composed of such learned or acquired *drives* The most thoroughly studied of these acquired drives is anxiety or fear (81) but numerous others have been mentioned (22,82,52) It was also recognized that objects can acquire reward and incentive value, leading to the notion of secondary reward or reinforcement (82) Because so much of human motivation is presumably learned, this theory provides well for the bewildering complexity of individual motivational factors while everyone may in learning obey the law of effect, what is learned by the law of effect will depend on the individual's particular situation and the

reactions he makes there His personality will consist of his acquired motives and other habitual characteristics learned under the law of effect

Without going further into the complexities of acquired drive and secondary reinforcement theory or into certain difficulties that can be raised concerning them we may return to the questions with which we introduced this chapter While the Hullian view could postulate drives for exercise and sport and while it has suggested that there is an activity drive (52) and even an exploratory drive (80) it has been prone to look to learned drives or to learned rewards to account for such phenomena as participation in exercise and sport Many children, for example, learn in our culture to value and to be motivated to engage in these activities Others may be lured by the high secondary rewards which our successful athletes often attain Yet others may find in sports and exercise a way of allaying other learned drives, like anxiety (see 15 for an analysis of the "drive" for money in these terms) And, withal, it must be recalled that even without drives toward or rewards from these activities if the habits that are involved in them are strong enough they sensitized by any active drive, will cause the person to act accordingly

Obviously, then, the view of motivation in exercise or sports that derives from this second class of theory is if anything more complex than that which went before No simple explanation is possible for these phenomena in terms of either class of theory both because their small numbers of basic drives become inordinately compounded through fusions and through learning, and because the same or similar behavior in different individuals may be motivated by similar or by entirely different factors

The two remaining classes of motivational theories are quite different from those just discussed they are relatively recent in origin, they assume multiple motives they reject tension reduction as the sole motivational principle, and they perhaps make motivation less a fundamental construct than even the second class of theory already described Neither viewpoint is as well worked out (especially in terms of the over all personality) as the other two classes or as definite or comprehensive in its scope They are included in this space, in order to represent the full range of current thinking about motivation and because the motivational pendulum seems now to swing in their direction

The Emphasis on Curiosity, Stimulation, and Manipulation

Hebb (45), Montgomery (84), and Harlow (43) are investigators whose work forms less a coherent viewpoint than it represents a concerted attack on two propositions which have fundamental importance to the two classes of theory previously outlined the notion of tension or drive reduction as the reinforcing or rewarding condition for learning and the assumption that the homeostatic drives, like hunger or thirst, are suitable models for the entire range of motivational factors Studies by his associates (10) which have

placed human subjects in conditions of severe sensory deprivation have led Hebb (45) to argue that there is a necessity for external stimulation, without it the subjects experience acute discomfort and show intellectual and emotional disturbance. Such evidence argues against a tension reduction theory, because the subjects were not comfortable in or tolerant of for very long a condition of minimal stimulation. Hebb (45) has also argued that curiosity and a general need for intellectual activity, for example, must be postulated in order to account for human interests in puzzles, games, and similar pursuits (for example, chess). Using rats, Montgomery (83, 84) has apparently demonstrated an exploratory drive which is independent of general activity and which seems to lead the organism to explore novel or unusual situations. For example, his rats came to prefer a pathway in a maze which led to a further maze of complex pattern over a pathway which led to a simple box. Since other rewards presumably did not operate, Montgomery suggested that the complex maze gratified exploratory tendencies, but this presumably involved more total stimulation than did the simple, empty

nanipulate simple puzzles

ulations, even when there

He believes that the puzzle arouses or elicits a manipulation motive and that the acts of working with the puzzle carry their own reward. Related to the work of these writers, Tinbergen (109) has stressed the role of external factors in releasing instinctive behavior patterns, and Nissen (89) has suggested that every separate activity must have its own motivation.

It is far too early to evaluate this work in terms of its overall effect on the theory of motivation, but in connection with the questions raised early in this chapter it would seem that this group might accept the proposition that exercise and sport may well have their own motives or reflect the general needs for activity, exploration, or stimulation.

While not directly related to or an outgrowth of the foregoing considerations, Young (118) and McClelland (72) have developed hedonic theories of motivation which could perhaps integrate the findings of the investigators into exploration, manipulation, and stimulation. McClelland has suggested

...

tion level. If the anticipated affective change is pleasant, he will be motivated, figuratively, to approach such objects or persons, but if the anticipation is unpleasant, he will avoid them. In this theory, all motivation is learned and the problems of drive reduction, secondary motivation, and reward are avoided. Much remains to be done, however, to make the theory testable and to determine through rigorous formulation whether it can actually deal with the facts. However, if exercise and sport are associated with pleasant affect, on this view we should expect people to show motivation

toward them On the other hand, one's experience with these activities could also lead to avoidance motivation No generalization about motivation for exercise and sports can perhaps be made since the goal values of such experiences would be heavily dependent upon individual affective experience with them as well as upon the present adaptation level

The Emphasis on Self Actualization

The last fifteen years or so have seen, both in psychoanalytic theory and elsewhere, developments which have essentially denied certain of the fundamental propositions of the first two classes of theories outlined above In psychoanalysis, these developments have consisted in part in less stress on biological and more stress on social determinants of motivational and personality patterns (104) Writers showing this trend include Kardiner (63), Fromm (34) Sullivan (103), Horney (50) (See 104 85,86,13,41) Certain of these writers have gone beyond this concern, however, and have embraced a notion which we shall here categorize as self actualization (34,50 78) A concept like self actualization is also prominent in certain recent and non psychoanalytic writers, such as Allport (3), Rogers (96), Snygg and Combs (100), Goldstein (37), Angyal (5), Riesman (95), and Maslow (77) Fundamentally, what is involved is the assertion that man must be free to express himself, his potentialities The factor seen to oppose this is anxiety and unsatisfied needs which make the individual conform to his social and cultural milieu Only by rejecting needless conformity and expressing himself can one, according to this position, attain a positive psychological health and grow further in the realization of his capacities

While there are many variations among these several writers in the formulations they present, we shall take as representative the position of Maslow (77) His statement is perhaps conceptually the fullest and most comprehensive account of such a position and he makes explicit many of its assumptions

Maslow suggests that there is a hierarchy of human motives or needs, with psychological health and full satisfaction in life possible only when one's chief motivation is at the top of the hierarchy The lowest order of these basic needs is the physiological—hunger, thirst, etc Next are safety needs, to be safe from threat and to be secure Further, there are the love and belongingness needs, those which require genuine affection and a place in one's

all these neec
status and to
higher needs,
wise holds that there are appropriate or required ways of satisfying these

needs, so that just any learned reward will not do At a stroke, therefore, he eliminates the concepts of acquired motives and secondary reward as not pertinent to fundamental motivational dispositions

The notion, further, is that for higher needs to appear and to be expressed, there must be some measure of satisfaction at the lower levels Thus a man *sorely pressed by the physiological needs is dominated by them and is not* free to seek affection, esteem, or self actualization Ideally, in the course of development, these lower needs would in large measure be gratified so that one would be unmotivated by them in any sense of domination and be free to pursue his own growth in the interests of self actualization Maslow seems to imply that most of the motives postulated heretofore by other theorists are not "good' motives and that health is a relative freedom of them, once they have received some degree of satisfaction In a sense, they are necessary evils on the road to self actualization

The self actualized man, then, would be motivated, if we may use that term, by personal goals arising from his own growth, and would pursue them without anxiety and without the necessity to conform, except superficially, to society's conventions and restraints

Maslow has applied this line of thought to exercise and sports For example, he has stated "All we have to do to open up this new area for research is to admit the possibility that play may be useless and unmotivated, a phenomenon of being rather than of striving, end rather than means" (75,302) But he has also argued that in this culture there is a tendency to force purposefulness upon behavior, as in the case of recreational sports 'An excellent illustration of the way in which our culture is unable to take its end experiences straight may be seen in fishing, hunting, golfing, etc Generally these activities are extolled because they get people into the open, close to nature, out into the sunshine, or into beautiful surroundings In essence, these are ways in which what *should be* unmotivated end activities and end experiences are thrown into a purposeful, achieving, pragmatic framework in order to appease the Western conscience' (75,299–300)

The writers of whom Maslow is representative would presumably accept

ably have no necessary drive in those directions However, Maslow would undoubtedly interpret most participation in sports and exercise as due to lower motives, defenses, and the like, for in his studies he has found relatively few self actualizing people and he has been unable to locate *any* young people who could be classed as such ("I had to conclude that self actualization of the sort I had found in my older subjects was not possible in our society for young, developing people," (75,200) One might observe in this regard that Maslow's self actualizing adults may be said to have "arrived" in life as far as achievement of culturally esteemed goals is con

cerned, whereas with young people there is necessarily much striving Except for youth s supremacy in sports and in physical prowess and beauty, achievement of this society s major rewards lies years, usually decades, of rigorous effort ahead

When the self actualizing man does exercise and participate in sports, he

narcissism

MEASUREMENT OF PERSONALITY AND MOTIVATIONAL VARIABLES

A great variety of techniques and procedures has been developed over the past 40 years for the assessment of personality and motivational characteristics Before attempting a brief description of some of the major classes of such instruments, we shall be concerned with two fundamental problems

Let us suppose that we wished to measure a man's weight The first measurement yielded by our scales is 150 pounds, a few minutes later we get 158 and a little later, 162 Trying a fourth time we get 145 Since all of the measurements have been made within a few minutes, and the man's true weight cannot have shifted as much as 17 pounds over this time interval, we would agree that there is something unsatisfactory in the measurement process We call it unreliable The difficulty may lie in the scale itself, in the way it is read, in the posture or stance of the subject, or in any combination of these

reliability

A similar problem arises when the measurement instrument is based on a judge's observation of someone s behavior Will the judge rate the same in observation? And other in the judg idge agrees closely with himself and/or with others can we conclude that the observational judgment has satisfactory reliability Psychological measurements simply have no value unless they give stable or consistent results when conditions

are such as to indicate no reason for change On the other hand they should not yield consistent results when the characteristic measured has changed, any more than a scale should report a constant value when a subject has been fasting for several days

This brings us to the second basic problem, that of the *validity* of measurements A measure can be highly reliable but even so, it is not necessarily valid Suppose we hypothesize that academic success in college is associated with the cephalic index, which can be measured reliably To determine its association with college success, however, requires a comparison of some measure of success with the cephalic indices for a group of students, the two measures may be totally unrelated In such a case the cephalic index would be invalid as a predictor of college success, or of the aptitude for college work, though it is highly reliable and may be a valid indication of other characteristics Alternatively a test of scholastic aptitude will ordinarily show some relationship to college academic success, so that it has some degree of validity, at least as a predictor of academic success There may be other situations, like the prediction of success in graduate school, or of performance in sports, however, for which the same test has little or no validity

As with reliability, there are several methods for assessing validity, which is to say that there are several types of validity We cannot go into these types here but references like Thorndike (106) or Cronbach (19) discuss these matters fully The essential point is that to use a test or similar procedure meaningfully we must know that it is a valid (and a reliable) measure of the characteristic in which we are interested for the population and under the circumstances which we are studying Extensive data concerning these facts as well as others concerning a wide variety of specific procedures may be found in the *Mental Measurements Yearbooks*, edited by Buros (17) Ferguson (28) outlines the general principles of personality measurement and analyzes representatives of several types

As indicated in the introductory paragraphs of this chapter, the chief research interests to date which have related personality and motivation to problems of exercise and sport have been these

1 characteristics which seem to distinguish different sports and other activity groups,
2 characteristics which differentiate outstanding performers from others, and
3 the effect of participation in or witnessing sports events on personality and motivational properties of participants or spectators

The first two problems imply a search for relatively stable characteristics which will differentiate activity groups and outstanding performers from others, the third problem implies measures sensitive and responsive to current experience While it is possible that evidence concerning all three problems may be obtained from the same instrument, it seems more likely

that a procedure suitable for one problem will not serve as well for the other This point should be kept in mind, as we review classes of tests and other procedures[2]

Procedures Consisting of Questions to Be Answered by the Respondent

This group includes a number of well known measures, as well as less well known procedures Within the class we can distinguish several kinds of procedures on the basis of the dominant kind of question included, although there is overlapping among the categories

1 *Biographical Information Blanks* These consist of relatively specific questions concerning an individual's past history A specific predictive task usually determines the selection of items for such blanks, and the worth of each item is usually assessed relative to its value in predicting the desired performance or other criterion Typically, then, a specific blank must be developed for each prediction or differentiation job, and the worth of each item must almost always depend on the particular prediction being attempted While a given blank thus has little generality, the method has been rather successful in forecasting such diverse criteria as employee turnover rate and amount of life insurance sold by salesmen It may be possible to examine the successful items and infer the kinds of personalities which succeed or fail in the criterion task, although the items used may not, in the first instance, hang together as a measure of any particular personality trait or motive pattern

2 *Symptom Questionnaires* A second kind of question content emphasizes symptoms, which the responde
and with what frequency For example,
of fatigue, unpleasant feelings, nightmar
and well being Such questions usually are found in adjustment scales, inventories, or questionnaires, like the Bell Adjustment Inventory, the Minnesota Multiphasic Personality Inventory, and the Personal Inventory An over all adjustment score is sometimes obtained, or in some instances scores may be provided reflecting different components and types of adjustment. These procedures perhaps have their greatest usefulness as screening devices, rather than as diagnostic instruments, and their validity has been seriously questioned by Ellis (24)

3 *Questions about Typical Conduct* A third kind of question often indicates conduct in a situation, and the subject is asked to answer concerning what conduct applies to him and with what frequency For example, the subject may be asked whether at a social affair he typically attempts to meet the

[2] ... discusses them in some detail (27, chaps 2, 3, 4 5)

guest of honor. Or the subject may be asked directly if he is shy or has difficulty in making friends; such questions imply a broader, characteristic behavior pattern, feeling, or response than is usually seen in questions of the first and second classes, above. A single trait, as in the Ascendance-Submission Reaction Study (Allport's), the Thurstones' Personality Schedule, or the Terman-Miles Masculinity-Femininity Test (which involves other items than simple questions), or several traits, as in the Bernreuter Personality Inventory, the Guilford Personality Inventories, and the Allport-Vernon Study of Values, may be "measured" by the test in question. The Study of Values tends to get closer to attitude-opinion-interest tests, as it requires the subject to agree or disagree with certain value statements in Part I and in Part II to rank alternatives which presumably relate to different kinds of values.

Most of the procedures representative of the categories outlined above have satisfactory reliability. Validity has not always been demonstrated (24), and it is often pointed out that a subject can fake his answers to create any impression he wishes. This factor can be controlled to some extent by requiring the subject to choose between two equally unattractive or equally desirable alternatives, only one of which has discriminating value relative to the criterion (28,316–321).

It seems likely that use of procedures like those outlined above might have value in descriptive characterizations of groups participant and nonparticipant in exercise and sport programs, successful and unsuccessful in such activities, and so on. However, judgments concerning the general adjustment or personality make-up of such individuals on the basis of these procedures should probably not be made and are probably unwarranted. Even a highly valid test of adjustment or of a personality trait could only be meaningfully interpreted in adjustment or trait terms for subjects who are closely comparable to the normative group on which the test was standardized.

The Use of Ratings

The questionnaire procedures outlined in the preceding section usually provide scores derived by counting responses; such scores may be converted to percentiles or to standard scores. We shall now turn to the use of ratings, which involve scores arrived at in quite a different way. Characteristically, ratings involve the use of a judge or judges who are asked to observe an individual in some situation and then to indicate on a rating scale the amount of one or more traits which he judges that the subject has shown. Thus one can observe another person in an interview or in a group situation or in some performance and rate him on a number of characteristics; the rating could be [illegible] not appear, or it [illegible] perfectly possible [illegible] equired in some of

the scales previously described) or for ratings to be made of individuals from memory or from a total impression And ratings can be used in many other situations as in the evaluation of work products, personal documents and so on However the principles of and methods for making ratings are essentially the same in a wide variety of circumstances (28) Characteristically two types of situations are commonly involved in personality assessment through ratings, as briefly described below

1 *The Interview* Interviewing procedures are perhaps the most widely used means for gathering data about individuals and for ascertaining attributes of personality (11 12) In personality measurement, interviews commonly provide impressions of personal traits (like friendliness, courtesy, etc) and inferences concerning underlying motives or dispositions thought to be more fundamental and significant than the superficial traits (Interviews are also sources of information concerning the individual's history, preferences interests and so on) The judgment of underlying motives however is often thought to require a number of interviews

In general evidence has ind cate

... the person will normally function, and the interviewer's own characteristics and biases will often color significantly the results obtained

Data which are reliable and often valid can be obtained when the interview is carefully and systematically set up and when careful attention is devoted to the judgments to be made and to how they are to be made A planned or structured interview is often required to insure that the same questions will be asked of all interviewees and a list of traits or items to be observed and a record blank on which the traits are to be checked or rated must often be provided to get satisfactory information It is impossible to generalize about the validity of personality ratings made from the interview, but it is often worth using when other less expensive, and more objective procedures cannot be used

2 *Performance and Other Situations* Ratings can likewise be used, as suggested in several places above, to systematize observations made of behavior in various situations, natural or otherwise Playground behavior of children for example, could be a read
rated f

... que as used by
... to be observed

or contrived circumstances have a certain plausibility as valid estimates of

personality traits, this plausibility is not uncommonly deceiving. For example, the OSS procedures had relatively little validity (90,28,64,101). In the field of personality measurement one can take nothing for granted.

Rating procedures can be modified in various ways. Forced choice techniques (28) may make them less liable to bias. Peer or buddy ratings can also be valuable, and one can often secure valuable information by asking the members of a group to nominate persons from the group whom they would rank high or low on performance, knowledge, or traits (28). In an effort to discover the actual bases for such judgments one can further ask for critical behavioral incidents (29) which the judge has used in deciding that, say, person A is a good leader whereas person C has little leadership ability.

UNSTRUCTURED (PROJECTIVE) PROCEDURES

Questionnaires and ratings are commonly employed to secure data on traits of personality, although in many instances inferences are also made concerning underlying motive states. The present group is used for estimating trait variables as well, but it is also commonly believed to provide valuable indices of underlying motives. These unstructured or projective procedures have had a rapid growth of acceptance and use in the last twenty years, especially in clinical psychology; their early use was primarily in the description of psychopathology.

Underlying all such procedures is the assumption that if a person responds to stimuli to which a response is not obvious or to which there are no right or wrong responses his responses will be determined largely by his own personal perception of the situation and the stimuli. This personal perception may be a product of his motives or needs. For example, suppose we show a person a picture of two people in interaction, but a picture in which the nature of the interaction, the relationship between the people, the nature of their thoughts and feelings, the purposes of their interaction, the history of their

are *imposed* or *projected* by the person on the pictures, inferences are then made concerning his characteristics and motives.

Almost any unstructured situation could conceivably be used in this way, and a wide variety of situations has been used. Some of the more common ones are as follows:

1. Ink blots, as in the Rorschach Test (7,65,98)
2. Pictures, as in the Thematic Apperception Test (110,72)
3. Incomplete Sentences, as in the Sentence Completion Test (48)
4. Drawings, as in drawings of the human figure (75) or in the House Tree Person Test (16)

Descriptions of a wide variety of procedures may be found in Allen (1), Anderson and Anderson (5), Bell (9), the Mental Measurements Year books (17) A cautious approach to the use and interpretation of such tests, especially the Rorschach, is presented by Sarason (98) (See also 71 and 74) Current research on these, as well as the other procedures discussed above, is summarized yearly in the series, *Annual Review of Psychology* (26)

There is yet a good deal of controversy concerning the reliability and validity of projective procedures Farber (25) has questioned the use of some of them as measures of motives, suggesting that they may tap habits instead Certain procedures are clearly susceptible to situational factors (98,71), and McClelland (72) has used this property in producing experimentally variations in scores derived for needs from the TAT Serious questions have been advanced in many other publications those by Windle (115), Holtzman and Sells (49), Kurtz (69) are perhaps indicative, if not representative

It is the best guess of the writers that conservatism is the best attitude with which to approach this kind of measurement Certainly, there seems to be no basis for the ready and uncritical use of projective procedures in just any situation or problem as reliable and valid measures of motive states or personality characteristics

This review of techniques for assessing personality and motivation has revealed a variety of procedures but it has also suggested serious questions concerning the ready applicability of any technique to a given problem in the area of exercise and sport Further, it has indicated that assessment in this area involves highly technical problems Perhaps the wisest conclusion would be that research directed to explore relationships between personality and motivation, on the one hand, and exercise and sport, on the other, must be truly multidisciplinary and collaborative

PERSONALITY STUDIES RELATED TO EXERCISE AND SPORTS

Instruments and techniques which have been developed by clinical personnel and students of personality have been used by a few physical educators and psychologists in an effort to determine (1) whether there are measurable differences in personality among various types of athletes or physical activity groups, (2) whether outstanding performers in sports have certain measurable and distinguishing personality traits, and (3) whether participation in or observation of play or sports ("sports spectating") gives rise to changes in personality dynamics Although in some instances they are merely pilot studies in unexplored areas, the major investigations of these kinds which have come to the present authors' attention are surveyed in the following discussion Moreover, a motivational basis for evaluating the meaning and psychological function of play and sports at different age levels

is suggested And finally, hypnosis is commented upon briefly in relation to the general field of exercise and sports

Personality Traits of Various Athletes and Activity Groups

It is commonly supposed that as groups, certain types of athletes have some identifying behavioral characteristics For example, weight lifters, fencers, tennis and golf players, and boxers are often singled out as being "types" Individuals associated with sports also commonly maintain that there is a "type' which is attracted by and another that is repelled by contact sports, another which is attracted by individual rather than team sports, another which avoids competition, and so on

Several studies have been undertaken in an effort to test impressions of these kinds Among the earliest of these was that of Henry (47) in which college students preparing to teach physical education track squad members, students enrolled in weight lifting, and student pilots were studied Examples of his findings are that the track men and aviators had nearly identical scores, that these two groups were significantly more neurasthenic than the physical education students, and that they were less introverted and hypochondriacal than the weight lifters More or less similar investigations involving various types of athletes and several different tests have also been conducted, and some differences in personality variables have been reported in all such studies Several of these representing different methods of approach are described briefly in the following paragraphs

Although Husman's study (53) of the aggression of athletes by projective techniques was concerned primarily with the *effects* of competition, he found that his samples of boxers, wrestlers, cross-country runners and non athletes had a number of distinguishing characteristics as far as aggressive tendencies were concerned Examples of his statistically significant findings are the cross-country runners tended to be more extrapunitive (i e, expressive of aggression outwardly) than the boxers, and the boxers who were one of the top college teams in the country, possessed less over all intensity of aggression than any of the other three groups, and had more superego (Rosenzweig) than the controls Further reference is made to this study in the discussion of effects of sports competition

Gold compared the personality characteristics of professional and college

and temperamental make up than either the professional or college tennis players (trait M), although generally speaking, all the groups were quite similar in most personality traits measured, the professional golf group was more socially extrovertive (trait S) than the varsity golf group, the college tennis players were less "nervous" (trait N) than the professional tennis

players the varsity golf group was less extroversive in its thinking than the professional tennis group, and indications were that all four groups ranked high in traits which are believed to be associated with good mental health. The investigator emphasized the severe limitations imposed on his study by the relatively small numbers of subjects used.

Recently, using the Minnesota Multiphasic Personality Inventory in a study of 141 athletes and 145 nonathletes of a single college, Booth (14) found some statistically significant differences in personality to exist between athletes and nonathletes and between participants in individual sports, in team sports, and in team-individual sports. Differences found included anxiety (*A variable*, i.e., the varsity athletes scored significantly lower than the freshman athletes, freshman nonathletes, and upper-class nonathletes), dominance (*Do variable*, i.e., the varsity athletes and the upper-class nonathletes scored significantly higher than the freshman athletes and nonathletes), and depression (*D variable*, i.e., the varsity athletes who participated in individual sports but not in team sports scored significantly higher than the athletes who participated in only team sports). The MMPI was judged by the investigator to be a satisfactory instrument for research of this type and it will undoubtedly be used in further analysis of this general problem. Further reference is made to this study in the discussion of investigation of superior athletes.

Perhaps more than any other group, weight lifters have been studied in an effort to analyze their personality traits, and in one study the researcher was also concerned with the question of why this activity has become so attractive to greatly increased numbers of American men.[8] These investigations are generally in agreement that body building (i.e., when done as an end in itself rather than as preparation for a sport or other activity) represents a compensation for feelings of inferiority, and on the basis of psychoanalytic and anthropological data Harlow has suggested that such feelings are widespread among modern American men because of the relatively small role that fathers play in the rearing and education of their sons—with all that this implies in relation to inadequate masculine identification and other possible sources of conflict (44).

Although there is a growing research literature dealing with the personality traits of various types of athletes, studies have not been done which justify generalization as to specific identifying characteristics of groups.

In the foregoing studies of activity groups such testing instruments as questionnaires, Smith's Human Behavior Inventory, the Guilford Introversion-Extroversion Scale, the Allport Ascendance-Submission Reaction Scale, the Thurstone Neurotic Inventory, the Guilford-Martin Inventories, and the Minnesota Multiphasic Personality Inventory have been used. In some cases parts of several different personality tests have been organized into a

[8] The title of this study is suggestive of its conclusions: "Masculine Inadequacy and Compensatory Development of Physique" (44).

single instrument Some projective tests have been utilized, including the Rosenzweig Picture Frustration Test, the Thematic Apperception Test, and some sentence completion items

No longitudinal studies seem to have been undertaken in an effort to de termine whether certain types of personalities merely gravitate into certain types of activities and/or whether participation in a sport is in part responsi ble for personality traits found

Personality Traits of Outstanding Performers and Champions

Champion athletes are sometimes called 'a special breed" for reasons other than exceptional physical attributes A few investigations have been made in an effort to evaluate the personalities of champion athletes One such study, representing a physical educator–psychologist collaboration, in volved both the Rorschach and the House Tree Person projective tests and, as subjects, twelve assorted contact and noncontact sports athletes of All American or national champion caliber (60) According to both tests the champions possessed several distinguishing characteristics which included extreme aggressiveness, a freedom from great emotional inhibition (which was interpreted to mean that they were able to express powerful emotions such as aggression relatively freely), high and generalized anxiety, high level of intellectual aspiration, and feelings of exceptional self assurance Obviously this sampling of champion athletes did not justify generalization of the findings

In another study a comparison was made between major league and minor league baseball players by means of the MMPI (69) Again, the ex ceptional performers were reported to have distinguishing traits including strong "drive" (expressed as ambitiousness and aggressiveness), self disci pline, initiative, and "a tendency to worry "

A third investigation also employed the MMPI to study athlete and nonathlete groups and to contrast good and poor competitors (14) Twenty two items of the MMPI were found to discriminate between the good and poor players of the college where the study was conducted and good and poor track men at a larger university The ability of these 22 items to dis- criminate between good and poor performance should be further studied, taking into account discrimination between other performance levels and possibilities for predicting future performance

The evidence to date suggests that exceptional performers in sports—like exceptional performers in science, combat flying, and business—have cer tain measurable and distinguishing characteristics However, there is no evi dence to indicate the extent to which these characteristics are "native to" the individual and/or are the result of participation in sports. It would ap- pear likely that existing or new instruments may be used to discriminate different levels of performance and eventually perhaps to predict champion levels of performance in so far as personality traits coincide with the neces

sary physical traits At present the differences in descriptive language of the various personality tests and the differences in levels of mental functioning with which they deal make accurate identification of traits and interest comparisons very uncertain

Effects of Sports Competition upon Personality Dynamics

Several precontest emotion studies have been suggestive of rather severe psychological upset (56 55 111), but only physiological indicators of emotion were used and thus no evidence was derived as to the effect of sports competition upon personality dynamics

A few studies have been conducted in an effort to determine the immediate effects and/or the effects of a season of sports competition upon personality dynamics In what appears to have been the first of these, Stone administered projective tests to college varsity football players before and after a practice scrimmage and after the football season (102) Stone was interested in obtaining evidence relative to either the circular or aggression reduction theories of overt aggression, and indeed seemed to find support for both theories That is, after the practice contest there was no evidence of reduction of aggression, although there was such a reduction after the season However, there may have been a somewhat naive assumption that football scrimmage is necessarily a clear-cut case of aggressive behavior; for depending upon circumstances—desire to make the team, failure to be noticed by coaches when good maneuvers are made, roughing by opponents, extended practice and/or other punitive action by the coach—a practice session can be highly frustrating and might at times be expected to heighten rather than reduce aggressive tendencies

A projective test of so-called total personality" (House-Tree Person) was used in a physical educator psychologist collaborative study of eight college varsity wrestlers (59) This study was undertaken in an effort to explore some rather fundamental questions related to the "cathartic" theory of sports and other notions of displacement and guilt reaction, and the impact of anticipatory stress upon personality functioning

The test was administered before the season at a time when the athletes were presumably in a normal and undisturbed state (Test I), within five hours of one of their season's most important matches (Test II), and the day after the contest (Test III)

In Test II there was what was interpreted to show a marked drop in the average functioning intelligence of the group, anxiety was heightened, and neurotic signs such as compulsiveness were rather prominent Indications were that aggressive tendencies were much more in evidence but more strictly controlled, and aggressiveness tended to be more inwardly rather than outwardly directed In Test III (postmatch), there was a restoration of normal functioning intelligence, marked neurotic tendencies were no longer

in evidence, and in most cases aggressive feelings were below Test I levels

In a subsequent study, Husman (53) concerned himself exclusively with the problem of aggression He administered the Rosenzweig P F study, selected TAT cards and a sentence completion test to four groups college varsity wrestlers, boxers, cross country runners (noncombative controls) and nonathlete controls His pattern of testing was pre and postseason and pre and post important contest His findings, like those of Stone (102), tended to support both the circular (i e, frustration aggression guilt reaction frustration, etc) and carthartic theories of aggression, and they shed interesting light upon the reactions of the four groups involved in the study For example, as a group the boxers, some of whom were regional and/or national champions, possessed less over all intensity of aggression, were less extrapunitive and more intrapunitive than the other subjects, and the cross-country runners were comparatively more extrapunitive and less intrapunitive and impunitive The tests employed in the study were by no means in consistent agreement as to results—which could be explained on the basis of the validity of the tests or the difference in levels of personality explored

among the wrestlers who lost more than 4 percent of body weight there was a statistically significant reduction in "extrapunitive aggression This type of study should also be done in relation to college and A A U level wrestlers who commonly lose considerably larger percentages of body weight in preparation for contests

In a pilot study involving a reexamination of the Husman study of aggression associated with college varsity sports, Paskalides looked for evidence of change in sexual tension after wrestling and boxing matches (91) Spontaneous verbalization of sexual material was found to be greater in the athletes than in the controls in all tests, and the lack of consistency in the direction of change lent no support to the popular notion that strenuous physical activity tends to lower sexual tension—that is, at any rate, when highly trained athletes are considered Although this study was dependent upon fortuitous material in an investigation designed for another purpose, the approach seemed productive and would appear to deserve further use

Spectators and Sports

The House Tree Person test was used to study the effect of a very exciting

—decrement in aggressiveness and hostility. Findings in this exploratory

research would seem to indicate the fruitfulness of this type of investigation for a more adequate understanding of the meaning of spectator sports

PLAY AND SPORTS IN RELATION TO MATURING AND AGING

It is well known that different stages of the maturing and aging process impose their own adjustment needs and problems, and we would therefore expect the motivation to play, exercise, and compete in sports to differ more or less at different age levels Moreover, illustrative of the fact that none of the several theories of motivation described earlier in this chapter can be regarded as having uniform application throughout life, Peller and other Freudians have distinguished between the symbolic play which releases Oedipal tensions of the infant and the experimentative and exploratory play (45) of the somewhat older child (92,78) And as previously mentioned, Maslow (77) has reported his inability to locate any self actualizing young people, and thus he is obliged to resort to deficit motivations such as those of striving and tension reduction to account for much if not most of the play, exercise, and sports of youth

In light of these considerations, it should be possible to trace a pattern of change in the psychological significance of play, exercise, and sports as transition is made from childhood to preadolescence to postadolescence to adult

undergoes change

Whatever else it may involve early childhood involves weakness, dependency, learning the ways of a complex and changing society, learning to restrain and control urges and impulses, and adjusting to an inconsistent and essentially adult kind of world During this period one might expect play to be associated not only with the theory of motivation proposed by such people as Hebb (theory number three, emphasizing curiosity, exploration, manipulation, etc) but also quite strongly with those theories stemming from such people as Freud and Hull (theories one and two, emphasizing

been a source of satisfaction to him" (67,1)

ciety tend to become the focal points of youthful aspiration—but their attainment cannot be expected even by the most talented and ambitious for years, frequently many years, of rigorous training and effort Only in such fields as sports and in activities dependent upon physical vigor and beauty is youth not asked to wait and may indeed attain rewards approximating his essentially adult aspiration levels When adulthood is reached and the society's major rewards become more available, striving takes new directions, and exercise and sports acquire new meaning What professional athlete would continue the frantic effort and rigorous discipline of his young adult years without the now primary reward of money?

On the other hand and again, of course, generally speaking, the period between the ages of about 9 and 14 (approximately school grades 4 through 8) is a time of relative fulfillment That is, increased body size, strength, and control and heightened ability to intellectualize and verbalize have made the life situation far more manageable, and many of the necessary compromises have been accomplished The innumerable frustrations of childhood are diminished It would seem that the theory of motivation proposed by Hebb (number three, exploration, curiosity, manipulation, etc) is more applicable at this age level than the more compensatory, or as Maslow terms them, "deficit' motivation theories This is a time of scouting, exploring, and camping and hunger for new skills of all kinds is phenomenal Assuming this interpretation to be in accord with reality, it would seem especially important that parents and leaders of youth of this age be aware of its psychology and avoid imposing the deficit motivation typical of later years upon the behavior of this intermediate group, as, for example, in sports competitions

It is possible that the observations regarding later childhood and early adolescence are also applicable to the advanced years of 'successful" persons That is, in their later years (or perhaps more accurately, if and when the society's rewards have to some degree been attained and/or a modified value system adopted) some persons apparently find play, exercise, and sports "ends" rather than "means," and engage in them for reasons proposed in the theories of Hebb or Maslow On the other hand, the "unsuccessful' adult or any adult who because of pressures and frustrations in his

[illegible]

professional boxing and professional wrestling) especially gratifying

Play, exercise, and sports would seem to have different meanings at different age levels, and thus when a life span is considered, a single activity may also have several different meanings—each of which seems to be more or less in accord with one of the theories of motivation described earlier in this chapter For example, the ancient sport of wrestling is to the infant a primitive combat, that is, tussling is resorted to solely as a means to an end

such as recovering a toy or displacing a competitor for a piece of game equipment Presently, it may also acquire the qualities of a delicious play-acting (or psychodrama) when done with one's father Somewhat later when wrestling can be conceived by the child as a sport, it is a popular but rather desperate and crude struggle to overpower, that is, the struggle is likely to be motivated more by the desire to win than by the fun of it However, to the pre and early teenager (about 5th to 9th grades), it is more likely to be a wholehearted test of skill in which winning and losing, as such, are relatively unimportant It is the doing, the controlled moving, the activity itself that counts—that is of course if adult pressure for winning is not imposed But to the young adult, the high school or college competitor, for example, the very essence of wrestling is dedicated preparation, grueling and meticulous training, and striving for victory And to those who participate in it for recreational purposes in adulthood, wrestling becomes a kind of relaxed bodily chess game employing clever strategems and maneuvers but lacking combativeness, great strenuousness or real concern over winning

We should add that professional "wrestling," with its brutishness, play acted violence, and great display of primitive and infantile emotion, is a distortion created entirely for the gratification of the audience

IMPLICATIONS FOR THE PLAY AND SPORTS CURRICULUM

Certainly, investigations are needed which will help those responsible for planning and directing the play, exercise, and sports programs of children, youth and older persons to select psychologically as well as physically appropriate activities and present them in such a way that they are in harmony with the dominant motivational tendencies of the age levels under consideration Ways in which play and sports may contribute to psychological health in the different periods of life should also be carefully explored experimentally and clinically [5]

HYPNOSIS IN SPORTS

Although hypnosis has commonly been considered a miraculous way of improving physical performance and has been utilized to some extent in connection with sports, perhaps its more interesting use is as a method of investigating certain aspects of personality dynamics and as a research tool in other types of investigations Its use in all three regards is discussed here briefly

It is known that under some conditions hypnotic suggestions can bring about extraordinary bodily and sensory changes, including anesthesia, altered kidney function, altered heart rate, cataleptic regidities of bodily parts, and altered visual and auditory perceptions (8,23,39,70,79,88,119 120,

[5] Psychoanalytic study of the play activities of adults, an area of growing importance for our mental balance today, remains to be done' (94,11)

121,122) In addition, strength and endurance performance levels have been raised and lowered by hypnotic suggestions

A few recent controlled studies having application to the effects of hypnotic suggestions upon such performance factors as strength and endurance have been reported In those of Eysenck (120) and Hammer (42), improvement was found to result from hypnotic suggestions, especially when fatigue was a factor However, a study by Roush seemed to have more direct application to exercise and sports (97) Strength and endurance were measured by means of hand and arm dynamometers and the hanging by hands test, and again, statistically significant improvements in performance were found to result when hypnotic suggestions were given under specified conditions including a very deep trance and posthypnotic amnesia Importance was also attached to the fact that suggestions were given that pain would not be felt (See also 8)

It has recently been observed that physically trained and untrained individuals seem to respond quite differently to hypnotic suggestions as far as strength and endurance are concerned In this preliminary work, large improvements in strength that have been observed have invariably involved untrained (athletically speaking) individuals, whereas athletes have not improved markedly in strength in response to hypnotic suggestions On the other hand improvement in endurance has consistently involved athletes but not untrained individuals A recent experiment involving all out effort of short duration (c 40 seconds) on the bicycle ergometer with athletes used as subjects revealed no improvement when posthypnotic suggestions for better performance and lessened fatigue were given (61) Properly controlled comparative studies of physically trained and untrained persons and of the effects of hypnosis upon prolonged endurance performance have yet to be reported

The use of hypnosis as an experimental tool is worthy of mention In many experiments the attitude of the subject toward the experimental variable may influence his performance For example, a subject conditioned to eat or not eat certain foods prior to exertion may be affected if his bias is violated, regardless of the actual physiology involved With properly trained subjects, posthypnotic amnesia seems to be a useful way of disposing of the *conscious* realization of whether or not the variable in question has been involved As an example of this use of hypnosis, in a study of the effects of "warm up" upon performance the subjects were hypnotized before each performance test, and before only half the tests and while in hypnotic trance "warm up" exercises were done (62) Posthypnotic amnesia obliterated all conscious awareness of what took place during hypnosis so that when the subjects took the performance test they had no conscious knowledge as to whether or not "warming up" had been done or, for that matter what the purpose of the experiment was

Hypnosis has been used in still another way in this general field A group

of Negro subjects was asked to write on the subject of "the Negro in sports and to comment on why winning in sports is important to the Negro These subjects were then asked to write on these same topics by means of "automatic writing" (i e, the subject's hand is instructed to write without the usual mental direction) while in a profound trance which was followed by posthypnotic amnesia The conscious and automatic writing materials were quite similar except that, whereas in the conscious writing sports and winning seemed important for their value in demonstrating equality of the Negro, in the automatic writing of the trance state, to some subjects success in sports also seemed important as a means of demonstrating basic humanness (' O, to be a person ') [57]

It is of great importance to emphasize a cautionary note in regard to the use of hypnosis There are many reasons why hypnosis should be used only by properly qualified persons who are fully aware of its technical aspects and several possible dangers

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29 EMMA M. LAYMAN

Contributions of Exercise and Sports to Mental Health and Social Adjustment

SUMMARY

Long before mental health *and* adjustment *became the household words they are today, physical educators, coaches, and recreation workers were thinking of sports and other forms of physical exercise as making important contributions toward increasing human happiness and improving social adjustment Some physicians, psychologists, and educational philosophers, too have long supported the contention that physical education and sports en*

today it is not easy to avoid mixing belief with knowledge, for four reasons (1) It is difficult to evaluate any program in the light of general mental hygiene principles, because many principles currently accepted by psychiatrists and psychologists are based on inadequately tested hypotheses which eventually probably will be modified or even discarded (2) The concepts of mental health and social adjustment are themselves so complex and involve such a variety of behavior patterns that they cannot be accurately measured or even estimated (3) Since mental health and social adjustment result from the sum total *of life experiences, they do not readily lend themselves to controlled experimental studies, hence, research in this area often yields results which are confusing or equivocal (4) The physical educator or coach like any other person who is 'sold' on his profession tends to be "ego-in*

to mental health and adjustment, with the results of modern research obviat

ing the necessity of relying on logical thinking, scattered case material and uncontrolled observations

On the basis of evidence now in existence the following appear to be facts

1 *The principle of mind body unity is a sound one and there is a close relationship between organic health and adequate adjustment If it can be demonstrated that exercise and sports contribute positively to the at tainment and maintenance of organic health it may be concluded that it will also help prevent poor mental health However it must be remem bered that the causes of maladjustment are many and just as immuniza tion against whooping cough will not prevent a ch ld from becoming ill with measles a sound physique will not necessarily guarantee the absence of unhealthy attitudes and socially undesirable habits*

2 *The acquisition of motor skills has been found to contribute toward meet ing the basic psychological needs of safety and esteem in young child en of both sexes and in boys and young men from the early grades through college years However for those with little aptitude for the development of motor skills experiences with physical education activities or sports may result in increased feelings of inferiority and insecurity unless the teacher or coach makes adaptations in the program which will enable even the most inept to attain success and prestige in the group*

3 *Supervised play presents potentialities for promoting mental health and for helping to prevent delinquency Several studies show that participation in athletics and extracurricular programs in school tends to be associated with good social adjustment Some studies of juvenile delinquency purport to show that programs of supervised play can reduce the incidence of de linquent behavior However other studies indicate that delinquents sel dom participate in supervised recreation programs and in fact do not want supervision of any kind Viewing all of the findings objectively it is apparent that having a supervised recreation program available in itself is not enough to prevent delinquency or to guarantee good adjustment Also many delinquents find their delinquent activities far more exciting and interesting than anything which is offered in the recreation program Supervised recreation can further better adjustment in children and ado*

not only group needs but the unique personalized needs of individual members of the group and small subgroups

4 *Evidence from play therapy and group therapy indicates that when play*

generally lacked a design which would make it possible to draw conclusions about cause effect relationships

5 *Exercise and sports supply outlets for the expression of emotions, and it has been claimed by mental hygienists that the outward expression of emotion in approved activities tends to provide a release from strain and to promote mental health In recent years, however, psychiatrists and others have pointed out that expression of an impulse such as hostile aggression does not necessarily reduce the force of its drive, and may even generate feelings of guilt as well as increase tension Psychotherapists have indicated that outward expression of emotion is needed, but that expression of negative feelings is therapeutic only in a context where it does not increase feelings of guilt, and when it can lead to self acceptance, self understanding and freer communications The value of expression of positive feelings through games and sports seems clear However, there is no conclusive evidence that expression of aggression through sports will necessarily make for better mental health, and some have questioned the contention that competitive athletics provide a release for aggression The creative dance has been found to be a type of activity through which an individual may release his feelings acquire some self understanding and communicate with others Nevertheless, it should be noted that for the creative dance to be of value as a means of expression it must be used in such ways that the individual can really be spontaneous*

6 *Under certain conditions competitive athletics may enhance learning social development and the acquisition of desirable personality traits From the mental health standpoint, varsity type athletics for boys appear to have no particularly harmful effects at the high school and college*

develop feelings of inferiority and inadequacy For most individuals, competitive athletics tend to favor the development of positive personality traits when the following conditions are met (a) interschool or varsity type competition is not a substitute for an intramural program, (b) individuals are encouraged to participate in activities in which they have some chance for success, (c) cooperation, loyalty, sportsmanship, and enjoyment of the activity are stressed, rather than the importance of winning, (d) losing a contest is not associated with blame and rejection and (e) competition is divorced from community pressure and hysteria It should be noted that most of the mental health benefits of competitive

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relatively informal atmosphere of the physical education class or recrea

tion group are conducive to the overt manifestation of personality traits which are often kept from making an appearance in the more formal and suppressive atmosphere of the classroom Therefore, because the physical education teacher, coach or recreation director sees personality "in action," he is in a position to gain valuable insight into the various mental health problems of children and youth Consequently, he can offer information contributing significantly to the "diagnostic" formulation which precedes a therapeutic program

8 *Physical education activities and sports provide a setting which is favorable to the development of discriminating values and socially acceptable character traits In sports it is customary to stress the desirability of sportsmanship, fair play, honesty, cooperation, teamwork, tolerance, and other so-called character traits, and to encourage their development However, it has been found that habit patterns developed and expressed in athletic activities do not automatically transfer to other situations In order for transfer to occur, the student must be helped to generalize about value concepts and must be motivated to apply them in all types of activity areas*

CONCEPTS OF MENTAL HEALTH AND ADJUSTMENT

In order to assess the mental health values of physical education and sports it is necessary to have a clear idea of what mental health is and how the mentally healthy person may be recognized A survey of textbooks on mental hygiene reveals that most writers on this subject shy away from defining mental health and prefer to describe the attributes of a mentally healthy person However, both attempts at definition and descriptions of attributes carry the implication that mental health is related to inner satisfaction and group acceptance In line with this concept, it has been suggested that mental health is that condition which makes it possible for the individual habitually to meet life problems in such ways as to provide him with a feeling of personal satisfaction and to contribute optimally to the satisfaction and welfare of the social group (110) Among the characteristics of the mentally healthy person frequently mentioned are peace of mind, relative freedom from tension and anxiety, a feeling of security, a sense of self worth, the ability to deal constructively with reality, enjoyment of human contacts, the capacity for mutual satisfaction in social relationships, integration around socially useful values, flexibility, an appropriate balance between self sufficiency and willingness to accept the help of others, the capacity to give and receive affection, the ability to direct hostile feelings into creative and constructive channels, the ability to accept present frustration for future gain, spontaneity, and the capacity to enjoy life These are some of the characteristics which enable an individual to meet adequately the demands of the social situation Considering mental health in a

social context, it may be said that mental health is expressed in social adjustment

The various formulations of the characteristics of the mentally healthy person have been based principally on studies of mentally ill patients and the changes which take place in them as therapy reduces anxiety and enables them to function more effectively These concepts have emerged from analyses of masses of clinical case material rather than being based on research designed to determine the characteristics of well adjusted persons However, supplementing the formulations based on clinical material is research in which the characteristics of well adjusted persons and interrelationships among these characteristics have been studied Such studies, using subjects of various ages, have been made by Goodenough (68), Koch (108), Hardy (73), Tryon (189), and McKinney (124) These studies have yielded findings tending to support those emerging from clinical studies of maladjusted persons

TECHNIQUES FOR ASSESSMENT OF MENTAL HEALTH AND SOCIAL ADJUSTMENT

In the studies which have attempted to evaluate the contributions made by exercise and sports to mental health and adjustment, various techniques have been used for assessing mental health and social adjustment Among the techniques and instruments used for this purpose are the following (1) personality inventories, (2) sociometric techniques, (3) ratings by teachers, (4) projective techniques (5) behavioral observations, (6) attitude questionnaires, and (7) psychiatric diagnostic studies In many of the studies

inventory and sociometric ratings

Personality inventories have been described by Cofer and Johnson, who indicate that these measurements of adjustment are of dubious validity [1] Ellis (51), reviewing many validity studies, originally expressed doubt of the value of such inventories for assessing either individual or group charac-

[1] See Chapter 28 for a discussion of personality inventories

them involve the use of other techniques to supplement evaluations by means of personality inventories

Studies on the factors related to mental health and adjustment have frequently mentioned the importance of status in the peer group for giving the individual a feeling of self worth An instrument which has been found useful for evaluating status is the sociometric test devised by Moreno (136), although originally it was intended as a device for measuring the amount of organization in social groups Several studies have shown this technique to have a high degree of reliability and validity (35,91,92,136,198) Breck (22) finds the sociometric technique quite applicable to the physical education situation, and it has become increasingly popular among physical education researchers in the past several years Although sociometry is a valid approach to the measurement of status, and status is one factor related to mental health and social adjustment, the studies using a sociometric approach do not clarify the varying significance of different kinds of status at different age levels and for different sexes For example, it would appear that team mate status might be of less importance for a college girl than for an elementary school boy, in terms of its significance for mental health

Before the development of modern techniques of assessment, teachers' ratings of character and personality were quite frequently used in studies of factors related to personality development Studies made of rating methods have shown that, when ratings are made by a single judge, they usually are too unreliable to be useful, and that for ratings to be accepted with confidence they should consist of the average of ratings made by several independent observers (180,95) Validity studies have pointed to distortions in ratings due to factors such as vagueness in definition of traits, acquaintanceship with subjects rated, and halo effects (180,108–113) However, Symonds has indicated that, with the application of certain principles, personality and character ratings may be accepted with confidence (180)

In those studies concerning the effects of exercise and sports on personality and character, wherein teachers' ratings have been used, the rating scales have conformed to accepted standards for such scales, but not enough judges have been used to make the ratings sufficiently reliable In defense of the use of these scales, it may be stated that in each case they have been used in combination with some other method of assessment

Since the publication of the Rorschach test (ink blot test) in 1921, "projective techniques" have increased in popularity among clinical psychologists, and in some clinical settings have entirely replaced the personality inventory for the appraisal of individuals[2] However, despite their usefulness for revealing personality dynamics, these techniques do have certain shortcomings and limitations when used for experimental purposes

[2] See Chapter 28

and for group comparisons Among these are the following (1) they do not lend themselves to the usual methods of establishing reliability and validity (2) many of the most useful results cannot be quantified, (3) idiosyncratic material for any given individual often cannot be lumped with idiosyncratic material given by another individual, (4) a high level of technical training and skill is necessary for interpretation of the results, so that nonpsychologists must make use of clinical psychologists as collaborators in studies utilizing these techniques As yet, no attempt has been made to utilize projective techniques to assess directly the effects of exercise and sports on mental health and adjustment However, several exploratory studies by Johnson and/or his co workers (89 99 100) have employed these techniques to study the effects of athletic competition on personality dynamics and such studies may have implications for mental health Results of these studies suggest that projective techniques, despite their limitations,

studies of individuals and constitute the basis for character and personality ratings observation itself also constitutes an independent method of study, with the observations being expressed in the form of descriptive summaries Much of the case material presented to illustrate the effects of certain kinds of experiences consists of such observational reports Studies in which evaluations of adjustment are expressed in this form are difficult to evaluate, since in most instances the observations are not controlled, it is not known how representative the behavior may be, and selective factors determining what behavior is to be observed and reported are not indicated The use of

by specific training propaganda superstition, and local prejudices, they are affected also by realistic experiences Hence, although they must be interpreted with caution, attitude inventories may produce results which are at least suggestive of the mental health values associated with certain types of experience

In some studies attempting to throw light on the effects of exercise and sports, normality is equated with the noninstitutionalized group and abnormality with the group which is incarcerated in a mental hospital or institution for delinquents There is undoubtedly some overlapping between the two groups in every study of this kind, so that some possible differences between normals and abnormals would be obscured When significant

differences *do* occur, however, and the groups are adequately controlled, it is probably safe to assume that the differences represent factors related to adequate or poor adjustment, although it cannot be assumed that this relationship is a causal one

In summary, a review of the techniques used for assessing mental health and social adjustment in relation to the effects of exercise and sports reflects the difficulties encountered in such assessment Some techniques have doubtful validity and reliability, some are useful only for rough screening, some measure only one aspect of adjustment, and some are affected by the professional competence or personal bias of the examiner or rater Nevertheless, because most studies use more than one technique for assessment and because most involve the evaluation of group trends the results can be interpreted as being at least suggestive of existing relationships In all probability, the situation reported above means that positive findings may be of more significance than negative findings

PHYSICAL FITNESS AND MENTAL HEALTH

The mind body relationship has been of interest to students of human nature since the early speculations of Hippocrates, Plato, and Aristotle, in the third and fourth centuries before Christ In more modern times, this interest has led to much hypothesizing about the somatogenic aspects of mental illness and the psychogenic aspects of both mental illness and somatic disorders This hypothesizing, and the clinical research which followed, eventually resulted in the establishment of a branch of medicine now known as psychosomatic medicine, which contributed to the fusion of the psychogenic and somatogenic points of view

Although psychosomatic medicine was at first dominated by the psychogenic view, present day specialists in this area tend to subscribe to a point of view variously designated as the 'holistic, organismic,' psychobiological," and 'psychosomatic viewpoint According to this orientation, as stated by Mohr (135), There is no such thing as a purely psychic illness or a purely physical illness, but only a *living event* taking place in a living organism which is itself alive only by virtue of the fact that in it psychic and somatic are united in a unity Thus the holistic theory contends that no physical or mental illness may be adequately diagnosed, understood, or treated unless it is viewed as both an organic problem and a psychological one (34)

Although the nature of the mind body relationship is still not adequately understood, there is ample experimental and clinical evidence that such a relationship does exist Jacobson's work on the electrophysiology of mental activities shows that thinking is accompanied by slight muscular contractions (90) Experimenters testing the physiological and psychological effects of drugs report simultaneous changes in both areas (105,119) Physiologists

have described the concomitant physiological and psychological effects of hormone secretions, and physicians utilize this knowledge in treating patients who present physical and psychological symptoms associated with climacteric changes Dunbar (48) has reviewed some 2400 studies showing that emotions involve bodily changes, that anxiety may result in physical illness, that organic illness may cause emotional problems, and that psychosomatic illness requires both medical and psychological treatment

During World War II there was considerable attention to the possible effects of physical fitness on morale Seashore (159), a psychologist, stated that all round physical fitness is important for morale because it provides a reserve supply of energy and habits of coordination which are necessary under the day by day stress of modern living, and during emergencies Sullivan (178), a psychiatrist, said that there is a lowering of morale whenever there is a relatively abrupt or rapidly supervening reduction in the functional efficiency of the body As specific conditions producing lowered morale he listed factors impeding the activity of the distance receptors so that the individual cannot hear or see as well as usual, sudden malnutrition, dehydration of body tissues, undercooling of the body, exposure to high temperature and humidity, and mild illness Physical educators have relied

day experience which demonstrates depression and discouragement accompanying illness, irritability associated with a head cold, and listlessness resulting from malnutrition However, more scientific evidence is available which shows that poor physical fitness may be related to poor mental health

Clinical case material indicates that maladjustments due to physical illness may be of three types (1) those in which symptoms are the result of pathogenic processes in the disease itself, (2) those which represent reactions to the discomfort of having the illness, and (3) those in which the reaction is to the experiences associated with the disease or resulting from it Among the experiences which may result in maladjustment are (1) satisfying experiences with illness, (2) experiences generating fear—fear of death, fear of injury, fear of the future, or fear of the unknown, (3) parental over protection, (4) long seclusion, with resulting withdrawal tendencies, (5) restrictions resulting in a feeling of being different, and (6) experiences causing certain illnesses to have a special symbol or significance for the patient

ems of adjustment, either

, cardiac disease, diabetes,

juvenile hepatitis, tuberculosis, polio, cancer, epilepsy, and encephalitis (21, 23,56,77,104,164) Kanner (104,154–155) points out that 'any serious or protracted illness which greatly impairs the health of the patient may be sufficient to precipitate mental illness, especially if the patient is unstable This complication may result from the action of toxins and from exhaustion as

well as from apprehension regarding the outcome of illness ' Hamilton (71) reported that in a survey of 200 patients complaining of 'nervousness," 46 were found to be reacting to mild, rather vague physical discomforts In these cases the curing of the annoying physical disorder resulted in the disappearance of the nervousness

During the depression, Layman (116) found listlessness, apathy, and educational retardation in malnourished school children and reported significant improvement in alertness interest, and educational achievement after the school began serving hot breakfasts Mateer (130) found a deficiency in glucose related to the development of irritability in children, with the irritability being eliminated by administering glucose

Most studies of children with physical handicaps show that on the average their educational achievement is below that of children without such handicaps, and they tend to be less well adjusted than unhandicapped children (24,27,32,36,81,144,152,177) However, some studies have indicated that this is not always true (9,25,84,103) Hardy (74), studying 316 children who were followed from the third grade to junior high school, reported that the incidence of disease was lower in poorly adjusted children than in the well adjusted or those of average adjustment although vigorous health and absence of physical defects tended to be associated with good adjustment Doscher (46) administered the Bell Adjustment Inventory to 99 physically handicapped college students, and found that they attained average adjustment scores, although an interview examination given 66 such students showed many unusual adjustment problems

More directly concerned with the relationship between exercise and mental health is a study by Weber (193) who investigated (1) the relationship between physical fitness as measured by the *Iowa Physical Efficiency Profile* and academic grades at the State University of Iowa and (2) the relationship between physical fitness and personality as measured by the Minnesota Multiphasic Personality Inventory The subjects were 246 male college fresh

tiphasic Personality Inventory

justment *If* physical exercise contributes toward improving organic health, it may in some instances result in improved mental health On the other hand, experiences making for superior physical fitness do not by any means render an individual immune to the effects of other types of traumatizing experiences in the home, school, or community, although it is by no means

inconceivable that excellent general fitness might contribute to an individual's ability to resist psychological trauma

ATHLETIC SKILL IN RELATION TO MENTAL HEALTH AND SOCIAL ADJUSTMENT

The importance of acceptance by the social group as a condition necessary for mental health and social adjustment has been repeatedly stressed by mental hygienists Most of the studies have shown that for boys from kindergarten through college athletic skill is related to social status and prestige, and makes other positive contributions to mental health This seems to hold true for girls in the elementary school, but as puberty approaches the athletic girl is identified with the "masculine girl" (10,57) and athletic skill seems to contribute less to social status Relatively few studies have used adolescent girls as subjects, but most of those that have involved adolescent girls have shown that athletic skills in adolescent girls tend to be related to teammate status but not to friendship status or more general social status

Jersild and his co workers (94,95) report that lack of physical skills is an important cause of fear among young children, and that development of such skills often results in elimination of fears

Rarick and McKee (146), using a case study technique based on interviews with teachers and parents, compared the adjustment of 10 third grade children with extremely high motor ability scores and that of 10 children with extremely low motor ability scores They found the children with superior motor ability scores to be active, popular, calm, resourceful, attentive, and cooperative, whereas those in the inferior group more frequently showed negative traits such as shyness, withdrawing tendencies, and tenseness Hardy (73) compared the characteristics of 38 elementary school children who were often mentioned as being well liked with those of 54 children who were seldom or never mentioned as being liked The popular children were markedly superior to the others in tests of physical achievement and as a group were unusually proficient in the type of playground activity commonly engaged in by boys and girls of that age

McCraw and Tolbert (121) studied the relationship between sociometric status and general athletic ability among 438 junior high school boys and found a moderately high relationship between athletic skill and status in the class, grade, and school Similar findings for junior high school boys have

[illegible] Jones (101) pointed out that on [illegible] of correlational evidence it may be concluded that for boys competitive athletic skills are among the chief sources of social esteem in the period preceding maturity, and that this is attributable not merely to the high premium

which adolescents place upon athletic proficiency, but also to the fact that strength and other aspects of physical ability are closely associated with such traits as activity, aggressiveness, and leadership He indicated also that physical abilities play a more important part in social adjustment with boys than with girls In a later study, Jones (102) made comparative case studies of the 10 strongest and 10 weakest boys in an urban school population involving 5 high schools Adjustment was evaluated by means of the University of California Reputation Test, cumulative records by staff observers, and cumulative records on a personal social inventory 'The summary for the ten boys high in strength indicated a tendency for strength to be associated with a good physique, physical fitness, early maturing, social prestige and social stimulus value, and an apparently satisfactory level of personal adjustment Similarly, the ten boys low in strength showed a pronounced tendency toward an asthenic physique, late maturing, poor health, social difficulties and lack of status, feelings of inferiority, and personal maladjustment in other areas" (p 707)

achievement, evaluating adjustment on the basis of teachers ratings, a sociometric technique, and the California Test of Personality It was found that students ranking high in athletic achievement demonstrated a significantly greater degree of personal and social adjustment than did students ranking low in athletic achievement Ondrus (142) made a sociometric study of a high school football squad and found a substantial correlation between social status and football skill

McKinney (123,124,125) has made extensive studies of the concomitants of adjustment and maladjustment in college students, identifying the adjusted and maladjusted on the basis of student ratings (124), the Thurstone Personality Schedule (125), and clinical evidence The concomitants of adjustment and maladjustment were determined on the basis of information obtained on questionnaires On all three studies it was found that the well adjusted student tends to have a good physique, is more skilled than the maladjusted, and has more frequent athletic team membership

Several sociometric studies have been made in the setting of the college physical education class for women Breck (22) studying 586 college women enrolled in different activity groups, found correlation coefficients ranging from 43 to 57 between *the skill and friendship factors affecting* status (Correlations are actually between teammate status and friendship status, and it appears likely that some students were selected as teammates on the basis of acquaintance and friendship, rather than on the basis of skill) Frost (62) and Fulton (63) found significant correlations between teammate status and volleyball skill, but Frost indicated that the correlations between friendship scores and skill in volleyball were not significantly greater than zero

In comparing the motor skills of women college students scoring high on the Minnesota Multiphasic Personality Inventory with those scoring low, Reid (149) found the motor ability of those with normal personality scores to be better than the motor ability of those with deviant personality scores

Bentson and Summerskill (12) studied differences in personal adjustment between 59 athletes who won letters in varsity sports and 59 athletes who did not earn letters, with adjustment being evaluated on the basis of record research and interviews They concluded that success in intercollegiate athletics does not have a generalized effect upon the adjustment of these students, but success in athletics is related to attitudes about athletics and self 'The successful athletes clearly felt that esteem on the campus was greater because of athletic achievement During the interviews, the letter winners expressed strong feelings of personal satisfaction resulting from their success in varsity sports They also expressed deep satisfaction with the social interaction and feelings of team spirit they had experienced' (p 14) Weber (193) studied the relation between scores on the Iowa Physical Efficiency Profile and scores on the Minnesota Multiphasic Personality Inventory, and found no relationship Henry (82) administered the Cozens General Athletic Ability Test and an interest and attitude inventory to 61 male college students He reported a positive correlation between general athletic ability and ascendance, particularly ascendance in physical situations

in [illegible]

m[illegible]

and Dehan (44) have indicated that [illegible]ter adjusted socially than nonathletes

Findings such as those reported in this section have commonly been interpreted as indicating the importance of skills from the standpoint of developing a feeling of self esteem, and the importance of developing intramural programs so that more students may have the status associated with team membership as a symbol of achievement

Schilder (156) offers case analyses to show that serious psychological problems may be based on difficulties with motility For example, he points out that problems originating in insecurity with reference to equilibrium may be factors in the later development of anxiety neuroses, and states that correction of deviating motor development is the indispensable basis for progress in psychological treatment

However, every physical educator or coach is familiar with the fact that [illegible]

[illegible]ences in body build and skeletal structure, many awkward children [illegible] youngsters with a mild degree of organic brain damage (45), and some are

individuals in whom motor dysfunction is a reflection of some psychological problem (13,127,197) Illustrating the latter, Bettelheim (13) cites case material to show how one child is unable to learn to throw a ball because he is afraid that if he learns, he will throw the ball at someone whom he wishes to hurt, another child is afraid to develop competencies of any kind because he believes that if he becomes skillful he will be held responsible and will be punished for an accident which has occurred years before Blanton (16) describes cases of college students whose awkwardness or incoordination is due to tension and anxiety Kubie (110) points out that competition in sports has very different meanings for the physically competent and the physically awkward child One will develop a sense of competence, adequacy, and eagerness to try new things The other will approach every new physical challenge with anxiety, and with the constraint and the exaggerated physical awkwardness which anxiety produces (p 11) Doscher (46) working with physically handicapped college students in a special class, reports that some students have been helped toward a better adjustment through experiencing success in physical education activities, whereas others have felt discriminated against—that the special class made second class students of them '

The implication of the demonstrated relationship between motor skills and social status is that a physical education program may contribute to superior mental health and social adjustment in those with a high aptitude for motor learning On the other hand, it may increase the frustration and anxiety of those for whom motor learning is difficult It is important, then, for the physical educator to be aware of this distinction and not proceed on the assumption that any physical experience automatically improves the social adjustment of all pupils for it is clear that certain types of situations may be damaging rather than valuable to some pupils unless the teacher takes certain precautions It is also important for the physical education teacher to be alert and observant so that he may detect those whose motor dysfunctions are a reflection of emotional problems and refer those students to someone who can give them professional help It is important also that the teacher have a knowledge of the types of skills which each student can

[illegible]

and testing than are usual in most school systems

PARTICIPATION IN PHYSICAL EDUCATION AND SPORTS IN RELATION TO ADJUSTMENT AND MENTAL HEALTH

Much has been written on the values of play and athletics for promoting the development of mental health and encouraging the acquisition of attitudes, values, and habits implied in the concept of good 'character" For

example, Cowell (39) states that "physical education, athletics, and recreation activities under wise guidance are valuable agents in preventive psychiatry' (p 143), and gives evidence to support this contention as he elaborates on it McKinney (126) reviews evidence that those who have grown up with limited play and companions are less well adjusted than if they had experienced a normal play life (p 414), and states the values of play as follows (1) it increases social poise and spontaneity, (2) it develops independence, (3) it releases tensions, (4) it forms the basis for friendship, popularity, and leadership (pp 194–195) Slavson (170) points out the value of active recreation for developing a feeling of self worth, which is essential to mental health (p 25) Bower (19) calls attention to the potentialities of physical education, recreation, and sports for developing such qualities as "personal and group integrity, loyalty, cooperation, courtesy, respect for the body, fairness, and that galaxy of traits known as sportsmanship" (p 80)

In evaluating the effects of physical education and sports on adjustment, most of the studies are such as to make it difficult to separate the effects of skill from those of participation, since the more skilled individual is more likely to continue participating than the less skilled individual, who tends to become discouraged and drop out

Bower (19) presents case material illustrating the use of game situations in the physical education class as a means of promoting the development of character in the elementary school However, Hardy's study (72) suggests that the nature of adult leadership rather than the activities themselves is responsible for mental health and character education values She studied the out-of school activities of well adjusted and poorly adjusted elementary school pupils, using information obtained by teacher ratings and observations, pupil interviews, and parent reports She concluded that "what children do with their after school hours is not an important conditioning factor in their personal adjustments" (p 467)

Cowell (37) made a study of junior high school boys, in which he compared the 'fringers' with those who entered actively into the common social big muscle play activities of the physical education program The groups were compared on the basis of a 'citizenship ballot," observation charts, and behavior trend cards (adapted from Marston) He found that students who are disinclined to enter wholeheartedly into the activities of the physical education program tend to have the following characteristics "1 They are less socially acceptable to other boys and girls 2 They tend to regard others as sor "

3

positions demanding qualities of virtue than are actives 4 They show a marked tendency to exhibit those negative behavior trends which psychiatrists, mental hygienists, and clinicians indicate are symptoms of great clinical value" (p 136) He concludes that "from the standpoint of social adjustment and happiness, fringer boys, in general, are against tremendous

cal education experiences on racial attitudes in high school girls Studying four activity groups (field hockey, soccer, softball and swimming), she found no significant changes in racial acceptance resulting from the physical education activities

Blanchard (15) reports on a comparative analysis of secondary school boys' and girls' personality traits in physical education classes In this study 132 children enrolled in physical education classes were followed over a period of 2 years, in the course of which each child was rated by classmates and teachers on a scale for the measurement of character and personality in physical education The results showed a continuous growth in desirable character and personality traits taking place with each succeeding grade level, with the girls' physical education classes for every grade level showing a significant superiority over boys physical education classes

In contrast to the findings of Blanchard, Milverton (134) compared personality trait ratings of 20 boys enrolled in a physical education class with those of 20 boys not taking physical education, and found no significant changes in either group over a 12 week period, except with respect to concentration, in which the experimental group showed some improvement

Smith and Nystrom (171) found that high school leaders participate more in extracurricular activities than nonleaders (The leaders and nonleaders were identified on the basis of teacher judgments)

Reid (149) compared two groups of college women with deviant scores on the MMPI One group had physical education three times a week for a

in this area of personality for this group

Duggan (47) made a comparative study of university undergraduate women majors and nonmajors in physical education with respect to interests, general information, motor abilities, and personality The physical education majors were found to prefer work and play of a daring, competitive, and out door nature, extracurricular activities sponsored by their own department, magazines concerning sports, and people who are daring; they have more varied interests than nonmajors, are indifferent to careless dress, are superior on motor ability tests, more stable emotionally, more extraverted, and more dominating Those majoring in other subjects prefer comparatively safe, noncompetitive, and indoor work and play, extracurricular activities of the language club and literary club type, magazines associated with the

example, Cowell (39) states that "physical education, athletics, and recreation activities under wise guidance are valuable agents in preventive psychiatry" (p 143), and gives evidence to support this contention as he elaborates on it McKinney (126) reviews evidence that those who have grown up with limited play and companions are less well adjusted than if they had experienced a normal play life (p 414), and states the values of play as follows (1) it increases social poise and spontaneity, (2) it develops independence, (3) it releases tensions, (4) it forms the basis for friendship, popularity, and leadership (pp 194–195) Slavson (170) points out the value of active recreation for developing a feeling of self worth, which is essential to mental health (p 25) Bower (19) calls attention to the potentialities of physical education, recreation, and sports for developing such qualities as "personal and group integrity, loyalty, cooperation, courtesy, respect for the body, fairness, and that galaxy of traits known as sportsmanship" (p 80)

In evaluating the effects of physical education and sports on adjustment, most of the studies are such as to make it difficult to separate the effects of [illegible] vidual is more [illegible], who tends to [illegible] drop out

Bower (19) presents case material illustrating the use of game situations in the physical education class as a means of promoting the development of character in the elementary school However, Hardy's study (72) suggests that the nature of adult leadership rather than the activities themselves is responsible for mental health and character education values She studied the out of school activities of well adjusted and poorly adjusted elementary school pupils, using information obtained by teacher ratings and observations, pupil interviews, and parent reports She concluded that "what children do with their after school hours is not an important conditioning factor in their personal adjustments" (p 467)

Cowell (37) made a study of junior high school boys, in which he compared the 'fringers' with those who entered actively into the common social big muscle play activities of the physical education program The groups were compared on the basis of a "citizenship ballot," observation charts, and behavior trend cards (adapted from Marston) He found that students who are disinclined to enter wholeheartedly into the activities of the physical education program tend to have the following characteristics "1 They are less socially acceptable to other boys and girls 2 They tend to regard others as socially more acceptable than they are regarded by other boys and girls 3 They are considered much less able by other boys and girls to fulfill school positions demanding qualities of virtue than are actives 4 They show a [illegible] from the standpoint of social adjustment and happiness, fringer boys, in general, are against tremendous

MENTAL HEALTH VALUES OF THE DANCE

The mental health values of music and painting have long been recognized, and these artistic forms were among the earliest to be used as adjuncts to psychiatric treatment in mental hospitals In recent years, recognition of their mental health values has resulted in changes in their manner of presentation in the educational setting, with less emphasis being placed on technique and more on use being made of art forms as media for self expression Despite these developments and despite the fact that teachers of the dance have always recognized the expressive aspects of all types of dancing, mental hospitals *have been slow to include it in their programs and teachers have*

conducted in mental hospital settings Examples are studies by Bainbridge, *et al* (7), Martin and Beaver (129), Bender and Boas (11), Chace (31), May (131), and Rosen (153) (The results of these studies will be discussed in greater detail in another chapter) These writers present case material to illustrate personality changes resulting from the dance program but these results are difficult to evaluate because no control groups have been used However, of significance from the standpoint of mental health are certain observations made about the nature of the experiences associated with the dance as revealed by the reactions of patients

Fehrer (54) reports on the use of dance therapy with orthopedically crippled children, and Bunzel and Bunzel (26) describe the use of the dance for improving the adjustment of normal children and adults Both articles include illustrative case material

The studies made seem to provide evidence that modern dance has po

ment for the expression of feelings, desires, ideas, conflicts, drives, fantasies, and defenses (7,11,17,26,31,129,131,154,155), thus (a) providing possible release of tension through catharsis (26), and (b) promoting greater spontaneity (7)

2 It is a nonverbal means of communicating with others, and so assists the *individual to relate to others and identify with others*

3 It helps the individual to acquire poise and confidence in social situations

4 It is creative and elicits reactions of approval from others, so gives the

, there has been a tendency
e," and because the dancer

must perform within the framework of an established pattern, rather than being free to establish his own pattern However, mental hygienists know that some persons can express themselves with more spontaneity in a relatively structured situation than in one where they have more freedom Such persons, when they skip, dance, clap, and whirl to the rhythm of the music, may be expressing themselves with an abandon which is not possible when they are free to express themselves in any way that they wish

Layman (115 226) reports the use of folk dancing as a means of improving the rapport and understanding between children and their foreign born parents, with the dances serving to help the children to appreciate the national heritage and background of the parents, and to improve communication between the older and younger generations

It has been suggested that for the dance to contribute to mental health certain procedures should be followed (1) The teacher should give instructions concerning fundamentals' and work on the development of skills at a time when the individual is not attempting to use these same skills for self expression Self-consciousness and spontaneity do not go hand in hand (2) The teacher must display an attitude of permissiveness with respect to the feelings which the individual wishes to express (3) Even when already prepared choreography is involved in a dance or the teacher has decided on a title or subject for a dance, the dancer should still be free to express his own feelings in the dance (115,371-372)

Although the potential mental health values cannot be disputed, actually the contributions of the dance cannot be specifically stated without controlled studies and more studies involving normal populations

COMPETITIVE SPORTS AND MENTAL HEALTH

There has probably been more heat generated in discussions and arguments about athletic competition—especially interschool competition and Little League competition—than about any other subject which is of concern to physical educators

It is generally conceded that competition itself is not necessarily evil, but that certain kinds of competition may be harmful to some persons, that competition is seldom beneficial to those who never have a chance to succeed, and that competitive programs which exclude a high percentage of possible participants cannot benefit those who are excluded

The tendency on the part of children and adults to be motivated by the incentives of rivalry and competition is not an inborn tendency, but one

proval and prestige (65 69,118,196)

Competition is inherent in many athletic activities and physical education teachers frequently inject an element of competition into noncompetitive activities to make them more interesting and to stimulate effort. Hence, it is pertinent to review some of the known facts about competition, particularly as they relate to mental health and adjustment.

Achievement and approval associated with achievement are important to an individual's feeling of self worth. Several studies have shown that regardless of the kind of activity involved competition is a very powerful incentive to learning, and children tend to learn more rapidly in situations where competition is involved than in those where there is no competition (69,87,128), but interest in cooperative activity is quite strong in elementary school children, and often if a group versus group contest is injected into a learning situation, some children will exert themselves even more than when they are working only for individual honors (88).

Although competition is a strong incentive to learning for the majority of elementary school children and continues to be an effective motivator in older students, there are individual differences in the responsiveness of students to competition. Some put forth great effort to excel, some remain fairly indifferent to competition, and others are so frustrated and disturbed by it that they are blocked in learning. In general, when an individual is always competing against those who are either far superior or far inferior to himself in ability, he is much less motivated to learn than when he is competing against others of about equal ability or against others only slightly better than himself.

Although it is generally agreed that competition is effective as a motivator for learning, especially in elementary school children, there has been considerable concern with the feelings, attitudes, and social behavior associated with competition. It has been frequently pointed out that competition is associated with hostility. In situations where children are vying with one another for a place on the team each child is threatening the status of another child. The individual who does not make the team may feel inferior, rejected, and resentful. When competition within the group is oriented principally toward competition for making the school team or competition toward attaining any other goal which can be attained only by a few, then many individuals will be disappointed. As pointed out by Gates (65), competition among individuals when other values are overlooked or subordinated tends to breed an indifference to others and enhance self interest. On

in the situation than competition. Also, under appropriate leadership, competitive situations represent situations where individuals may learn about fair play, teamwork, and sportsmanship.

Fraleigh (59) surveyed the literature relating to the influence of play upon social and emotional adjustment and concluded that "skillful participation in the normal pattern of social and competitive play is generally associated with better adjustment, while participation in individualized, less competitive play is associated with poorer adjustment" (p 495)

The Joint Committee on Athletic Competition for Elementary and Junior High School Age prepared a set of questions relating to the psychological effects of "high pressure" athletic competition on children and submitted the questions to 31 psychiatrists, psychologists, and experts in child growth and development For the most part, the experts felt that the effects of competition could be beneficial or detrimental, depending on the attitudes and values of adults and the needs and personality characteristics of individual children It was pointed out that failure has different meanings to different persons—that some take it in stride, others are stimulated by it, and still others react with feelings of inferiority and discouragement There was agreement that if benefit is to accrue from competition, it must be set up so that there is no blame for failure Most experts felt that "high pressure" competition was undesirable, and likely to result in a distorted sense of values Some of the authorities expressed the opinion that competitive athletics could provide a needed release of aggressive impulses, but Lemkau questioned this, in the light of the rules by which athletes are bound in game situations (5)

Those who have been opposed to "varsity" type competition below the senior high school level have cited evidence to show that anxiety and excitement about important contests results in restless sleep similar to that produced by frightening television shows or other upsetting experiences (141)

Using a revision of the McCue attitude scale, Scott (158) made a study of the attitudes of parents, teachers, and school administrators toward intensive athletic competition at the elementary school level (4th through 6th grade) The results showed considerable difference of opinion but all three groups

of adults

Three studies (161,165,166) throw light on the mental health implications of Little League and Middle League Baseball for boys of elementary school and junior high school age Skubic (165) used the Galvanic Skin Response as a measure of emotionality in testing the responses of boys immediately before competition, immediately after competition, and one and one-half

hours after competition Her subjects were 75 boys who participated in Little League Baseball, 50 boys who were members of Middle League teams, and 80 boys who participated in softball competition in physical education classes She found that insofar as the Galvanic Skin Response test can be taken to be a valid measure of emotional excitation of boys of this age level, youngsters were no more stimulated by competition in league games than they were by competition in physical education games In a questionnaire study of the attitudes of parents and players toward Little League and Middle League competitive baseball, Skubic (166) reported that boys who were members of such teams were better adjusted socially and emotionally than boys who were not members of teams, but that the sleeping and eating habits of many of the boys were disturbed due to the excitement of the games Seymour (161) compared the behavioral characteristics of boys who participated in Little League Baseball with those who did not, using the SRA Junior Inventory, teachers' ratings, and the Ohio Social Acceptance Scale as measurement instruments Both groups were evaluated prior to and subsequent to the playing season There was little difference in the number of problems manifested by the groups The participants scored slightly higher each time on personality traits and received higher social acceptance ratings than the nonparticipants However, with the exception of the trait of leadership, changes occurring as a result of participation were not statistically significant

McGee (122) studied the attitudes of parents, teachers, and school administrators toward intensive athletic competition for high school girls The study was made in one community sponsoring such competition, and two [illegible] teachers were less favorable than parents and coaches All three parental groups had positive attitudes, with those being strongest in the community having a competitive program All agreed that outcomes in the areas of personality development and human relations were among the most favorable

Bell (10), on the basis of a personality inventory, a sociometric test, and a questionnaire, found that high school girls participating in interscholastic basketball were higher than nonparticipants in participation in other extracurricular activities, number of elective offices held, popularity, social acceptance, and self acceptance, but were also less feminine and more impulsive

Stalnaker (176) studied the attitudes toward intercollegiate athletics among University of Minnesota faculty members, University of Minnesota students, college and university presidents, University of Minnesota varsity athletes, alumni of the University of Minnesota, newspaper editors of Minnesota, the general public of Minnesota, and the parents of University of Minnesota students On the average, all groups were favorable in their atti

tude, with athletes being the most favorable and university presidents the least Among values mentioned by athletes are those pertaining to personality and character variables

Several studies by Johnson and his co workers (76,89,96,98,99) have dealt with emotional changes associated with intercollegiate contests in various sports, including football (76,96), wrestling (89,98,99), track (76,89), boxing (89), swimming (98), basketball (98), and hockey (98), using various means of assessing emotional changes, including introspection (96), Galvanic Skin Response (96,98), other physiological changes (96), word association test (98), and projective techniques (89,99) In most of the studies more than one technique was used to measure emotional change It was found that emotional disturbance preceding athletic contests is of sufficient intensity to be measured by any one of a number of techniques, but that after the contest is over the disturbance subsides It was Johnson's impression that ' the 'disturbed state' which so commonly characterizes the precontest situation is probably not detrimental to individuals who are comparatively free of profound personality disturbances" (98, p 432) Johnson and Hutton (99) found a decrease in aggressive tendencies in wrestlers the morning after competition, but made no statements concerning the implications of this for mental health

Hazelton and Piper (79) used a questionnaire to evaluate the attitudes of freshman college women with respect to certain social traits, and they com

students taking individual sports However, this may have been the result of participation in a team sport or it may have been a factor related to the selection of an activity of this type

In summarizing the mental health implications of competitive athletics, the following appear to be true

1

interests and feelings similar to his In doing this, they help to promote the development of interest in others, understanding of others, and sympathy for others

2

but who think of the team as 'our team"

3 Competition is a powerful incentive to learning for those who feel that

they have any chance of winning For those who are always losers, it may be a deterrent to learning

4 Individuals competing for places on a team may develop strong hostile feelings toward one another This may be partially corrected by emphasis on concepts such as sportsmanship and friendliness but in younger elementary school children excessive emphasis on competition may interfere with the development of socialized concepts

5 From the mental health standpoint, intensive competition at the elementary and junior high school levels seems to benefit some participants but may have detrimental effects on others (This does not invalidate or belittle the potential harmful effects in terms of physiological functioning and safety mentioned by some investigators)

6 Varsity competition in high school and college is associated with precontest emotional disturbance, but this does not appear to have an effect on the general mental health of participants

7 Overemphasis on varsity type competition and underemphasis of intramural competition or the general physical education program limits the benefits of competitive athletics to a few, and may leave many individuals with a sense of inadequacy or failure

8 Beneficial effects from competitive sports are most likely to occur (1) when the program involves varied activities, (2) when it is such as to make participation available to all, (3) when approval is given for cooperation, sportsmanship observing the rules and trying hard, (4) when joy in the activity is stressed and the importance of winning is de emphasized, (5) when competition is not surrounded by community hysteria and the loser need not fear blame or rejection when he makes a mistake, and (6) when it is under competent professional leadership

SPORTS, RECREATION, AND DELINQUENCY

In the literature on crime and delinquency considerable attention has been given to the possible relation between physical defects and delinquency, and the values of supervised recreation in the prevention of delinquency

Burt (27), studying juvenile delinquents in London, found 70 percent suffering from physical defects Schumacher (157) reported similar findings for delinquents in Cleveland Christie (32), comparing the incidence of physical disabilities in 282 unselected boys from a junior high school and 282 consecutive cases examined at the San Francisco Juvenile Detention Home, found that the incidence of physical defects was significantly greater among the delinquents than among the normal boys Some psychologists—especially the followers of Adler (2)—have made much of organ inferiority in relation to feelings of inadequacy, and have interpreted delinquent trends in certain individuals as attempts at gaining superiority If physical

defects have some etiological relation to delinquency, then any program which promotes physical fitness would be considered to have value for helping to prevent delinquency. However, Schumacher (157) and others have pointed out that delinquency rates are highest among the economically and socially inferior groups of the population, and that physical defects tend to be most prevalent in such populations, whether delinquency rates are high or not. Furthermore, surveys made by the Gluecks (66) and by Healy and Bronner (80) have shown no significant differences between delinquents and nondelinquents with reference to physical condition. Studying 500 delinquents and 500 nondelinquents from the standpoint of body build, the Gluecks (66) reported that "the majority of persistent juvenile delinquents are typically of the mesomorphic, muscular, well-knit athletic type (p. 102), more harmoniously organized for direct physical activity than non-delinquents, probably making easier the conversion of impulse into action. Healy and Bronner (80), studying delinquents in two cities, found them more skillful and active in games and sports than nondelinquents. Murray (137), comparing delinquents and nondelinquents, found delinquents inferior to nondelinquents with respect to knowledge of rules of certain athletic sports, but found the two groups about equal in athletic performance.

One of the major arguments advanced for the establishment and support of [illegible]

[illegible] quents or potential delinquents whose spontaneous play interests lead them into antisocial activities. Persons such as Nolan (138), Deputy Commissioner of the Police Department in New York City, stress the value of athletics in helping to prevent delinquency by developing qualities such as a respect for the rights of others and the importance of fair play.

Studies designed to test the effectiveness of supervised recreation programs

covered by the study was three times as high as the similar rate for nondelin

of juvenile delinquency in
of recreation programs, in
vestigators such as Thurstone (186), Powers and Witmer (145), Shanas and Dunning (162), Fine (55) Reinhardt and Harper (150), Kvaraceus (112), and the Gluecks (66,67) show that even when recreational facilities and supervised programs are available most delinquents neither take advantage

Both this study and a study which Thrasher made at the Boys Club of New York University (185) showed that even those children participating in supervised programs were more likely to become delinquent as they grew older

Considering the conflicting findings reported, it would appear that they are due to differences in leadership and organization in different recreation programs, differences in the kinds of statistics studied, differences in general community characteristics, and differences with reference to other delin quency prevention programs which are in existence Truxall (188 123) has warned that "it is entirely wrong to ascribe the reduction in the amount of *delinquency in a given locality to the introduction of a recreation program* unless it is known that all other factors in a given situation remained constant"

Despite the confused picture with reference to supervised play and juve nile delinquency, certain generalizations seem fairly clear

On the negative side of the ledger

1 Being a good athlete or being physically fit is no deterrent to delin quency

r

dren who are presumed to need them most

3 The total time spent by any child in supervised recreation is not enough to reduce appreciably his opportunities to engage in delinquent ac tivities

4 For children who have come to enjoy their delinquencies as games, the thrills thus provided are usually much greater than those which organized recreation can provide

5 As pointed out by Tappan (150,183), the existence of a play group may itself help to stimulate its members to engage in delinquent activities, engaged in 'for fun' after the supervised activities are over

6 As stated by Glueck and Glueck (66,197), " it is futile to treat the child, delinquent or otherwise, apart from the family that contributes

much to make him what he is Without concentration on the family, particularly the parents, we may set up boys' clubs, recreational centers, clinics, and the like, and we may inveigh against the movies, comics, and crime-suggesting toys, but we shall still be trying to sweep back the tide of childhood maladjustment and delinquency with painfully inadequate brooms'

On the positive side

status

2 Although recreation cannot cure or prevent delinquency, it can and will help *some* potential delinquents

3 Supervised recreation has a valuable contribution to make in a community program which also includes attention to factors in the family and home which are intimately related to delinquent behavior

4 An athletic or recreational program, planned as 'group therapy," taking into consideration the needs which delinquency serves as well as the motivations and educational processes related to delinquent acts, may be most effective in preventing or correcting delinquency among children involved in such a program (183)

Various suggestions have been offered, for making recreation programs more effective from the standpoint of delinquency prevention (1,66,150, 172) Among them are the following

1 Have more recreation programs without cost
2 Have year round programs
3 Have more programs for girls
4 Glamorize teenage programs
5 Have better adult leaders
6 Give more adequate training to adult leaders, from the standpoint of providing background in psychology and sociology particularly as they re-

means of attracting potential delinquents such as contacting group leaders, becoming friendly with gang members, establishing groups where the gang hangs out, having mobile recreation units and developing programs which will avoid those elements of which the delinquent is likely to be suspicious

8 Establish more programs based on a consideration of individualized therapeutic needs

PLAY AND PHYSICAL EDUCATION IN DIAGNOSIS AND TREATMENT OF MALADJUSTMENT

play activities, child guidance workers have come to recognize the value of play observation as a means of gaining an understanding of the child, and it has become standard practice to conduct psychiatric interviews with children in a playroom setting Those who advocate use of play observation as a diagnostic technique recognize play also as a form of treatment for maladjusted children Sometimes this treatment involves only a single child and the therapist, but often it takes place in a group setting Whether it is individual therapy or group therapy, however, it involves recognition of individual needs and planning to meet those needs There is much case material to document the claims that play therapy does result in improved adjustment of unhappy and maladjusted children (3,6,59,168,173 192)

It is frequently pointed out that because of the nature of the activity program and the relatively informal atmosphere of the physical education class or recreational athletic group, the gymnasium and athletic field are places where one sees "personality in action'—where basic characteristics are revealed in a manner which is not possible in the more formal atmosphere of most classrooms For example, Cowell says, Weaknesses and strengths are readily spotted Physical cowardice, sissiness, fearfulness, or nervousness becomes evident Here teachers get a much more adequate view of personality in action than can be obtained from the narrow confines of the clinical laboratory, the classroom alone, or 'paper and pencil tests purported to measure personality Furthermore, the informality of the student teacher relationship in physical education and athletics is of unusual value for effective guidance" (39,145) Layman (115) and LaSalle (113) list specific behavioral items to be observed in the physical education class, which may reveal useful information about personality characteristics and adjustment, and Layman (115) gives case material to illustrate the value of such observations as an aid in understanding patterns of maladjustment

education and athletics (115) However, the explorations of the psychodiagnostic and psychotherapeutic potentialities of physical education and athletic activities are still in their initial and nondefinitive stages

DISCUSSION AND RECOMMENDATIONS

The majority of the studies reviewed in this chapter point to the conclusion that exercise and sports have potentialities for contributing positively to the attainment of mental health and for the acquisition of behavior patterns making for social adjustment However, there are indications that under some circumstances, with some groups, and for certain individuals, physical

education and athletic activities seem to be unrelated to the development of mental health, or may be detrimental to it

Somewhat confusing are the conflicting findings reported by researchers making comparable studies of similar groups, and the fact that in the same study different measures of adjustment may seem to show opposite trends Possibly partially accounting for the conflicting findings reported by different investigators are differences in programs and teaching methods, as well as inability to control factors such as the personality of the teacher or coach, the nature of the teacher student or coach-player relationship, and experiences stemming from influences in the home and community It is known that school age children often tend to identify themselves with a popular teacher or coach and not only take on some of his characteristics but change some of their behavior patterns to please him (93,182) Studies of teacher pupil relationships show that children whose teachers are warm, friendly, and encouraging tend to be better adjusted than those whose teachers are cold, aloof, and critical (181) Research in the field of character education shows that teaching methods have much to do with whether or not character traits developed in one situation will transfer to others (115) The possible effects of "community hysteria" on the football or basketball varsity player have often been hinted at, but never really studied

The apparent inconsistencies of findings in the same study as well as conflicting findings in different studies perhaps may be partially accounted for on the basis of several factors related to the instruments used and interpretations of statistical results (1) On different personality tests the same trait names are frequently used for entirely different constellations of behavior patterns (51) (2) Some tests seem to tap different 'levels" of personality than other levels (97), so that one test may be getting at unconscious feelings, another at conscious feelings, and a third at feelings translated into action These would not necessarily be in agreement For example, unconscious aggressive impulses may not be translated into aggressive action (3) An individual whose adjustment is being evaluated by different means may not appear the same to his teachers, his peers, and himself In situations where teacher ratings and self appraisal techniques are used, it might be expected that the results would not be in entire agreement (4) Because of the complexity of the concepts of mental health and adjustment and the impracticability of attempting to evaluate them [illegible] nt
studies have dealt with different fa[illegible] r
relations between th[illegible] d
with me[illegible]

[illegible] (5) Varying interpreta
t[illegible] statistics For example, the results of the
st[illegible] and delinquency made by the Chicago Recreation Com
m[illegible]on (162) have been interpreted as indicating both that supervised

recreation can help prevent delinquency, and that it has no effect on the incidence of delinquency (6) Concomitance or correlation are often mis takenly interpreted as indicating a cause effect relationship between two variables, whereas in some instances causal factors may include uncontrolled factors other than those being studied

Despite the confusion in the picture, it is fairly clear that certain condi tions must be met if programs of exercise and sports are to make positive contributions to mental health and social adjustment Among these condi tions are the following (1) The activities should be such as to encourage the development of organic health (2) The activity program should be available to all, and not to just a small, select group of super athletes ' (3) Activities should be geared to individual differences in ability and inter ests (4) Physical education teachers and coaches should avoid profes

system of values and toward meeting the unique, individualized emotional needs of each member of the group

In order to clarify the picture with reference to the relation between ex ercise and mental health, more research is needed The following suggestions are offered (1) Do more studies with girls and women as subjects (2) Do some experimenting with *individually prescribed* exercise to meet the emo tional needs of specific children and adults (This type of experimentation is being done by corrective therapists working with adult patients in mental hospitals

or recreati

can be coi

many studies involving explorations of relationships between exercise and different specific aspects of mental health and adjustment, rather than rely ing on an omnibus or shotgun ' approach to the problem of assessing men tal health This would lead to a more accurate picture of the specific effects of certain activities or methods of teaching The sociometric studies of so cial status represent one type of study of a specific aspect of adjustment (5) Use several instruments for measurement of each particular trait being

-rent aspects of ad

, and that the data

such as the MMPI,

which is interpreted in terms of profiles ' and interrelationships among factors, attempts to demonstrate the effect of exercise on the scores for in dividual factors would be expected to yield negative results) (7) Plan more

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30 GRANVILLE B JOHNSON, JR

Motor Learning[1]

SUMMARY

Some significant research on motor learning was done by James and Thorndike around the turn of the century However, World War II stimulated considerable research because of a need to teach men to manipulate the instruments of war This work has been continued, even taking into account extraterrestrial conditions, as preparations are being made for the exploration of outer space Still, many important questions remain for future research to answer

Review of the psychological and physical education journals indicates lit

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phenomenon, describing it, setting up conditions for its replication, then devising a system which summarizes, integrates, and explains the facts, the physical educator appears to place greatest emphasis on fact finding and measuring devices In other words, the physical educator's research is apparently not theoretically oriented Moreover, the two disciplines seem to lack awareness of progress and problems in each other's areas, even though it is absurd to suppose that they have no relevance to each other

It is generally held by psychologists that both verbal (i e , symbol manipulation) and motor learning follow the same general laws and the phenomena of each may be explained by a single system However, some phenomena of learning show up better where verbal or motor reactions are studied, and therefore the dichotomous terms are justified on grounds of con

[1] This chapter is primarily a review of the research (of the past ten years) on motor learning in physical education and psychology, and explanation beyond the review is provided merely to give a frame of organization

venience, even though the psychology of motor learning is one with the psychology of learning

In this chapter learning theory is discussed in relation to systems which have been evolved to predict behavior over a wide range of conditions, and in particular the work of Hull is noted

Measurement of motor learning is discussed with reference to major problems, including indiscriminate use of terminology, as well as specific procedures that have been utilized, i e, statistical analysis of existing tests new measures of motor learning prediction of performance, factor analysis and measuring devices to examine theoretical constructs

Factors significant to motor learning are outlined and have to do with (1) characteristics of the material learned, (2) characteristics of the learners, and (3) the mode of presentation of the material to be learned Each of these is dealt with in terms of general considerations and recent developments Taken into account are such matters as meaningfulness of the material to be learned and transfer, physiological state, age, sex, intelligence, and race of the learner, and distributed and massed practice and whole-part learning

INTRODUCTION

Around the turn of the century some significant research was begun to explore the phenomena of motor learning The pioneer research was done by James (36) and Thorndike (70)

World War II stimulated considerable research necessitated by the practical consideration of isolating and identifying the variables significant in teaching men to manipulate the instruments of war At the present time
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methods of measurement, means of handling data, and theoretical systems

In a recent paper (presented to the College Physical Education Association Convention, January 2, 1956), Henry reviewed the needs of research on motor learning In this review he pointed out that we are profoundly ignorant as to the quantitative aspects of learning in our instructional classes He hypothesized that the reason for this was not a lack of measurement techniques, but lack of interest and 'unwillingness to do the hard and detailed work that is necessary to secure the extensive information that is needed'

He went on to say 'It may be hoped that in the next five or ten years we

will see the publication of basic data on the day-by-day and week by week *improvement* of students in our classes, at *various age* levels and for *typical teaching techniques* [Italics added] He pointed out that the emphasis should be on *what is actually happening in the children rather than just the techniques* we use to teach them Of course *new evaluation methods* would necessarily be developed'

He maintained that general problems basic to our curricular philosophies need direct attack He gave as a major example the question of specificity To what extent are we justified in believing that there is a quantitatively important general factor of motor learning ability? If we are forced to a multifactor theory, how great is the specificity, and does it vary with age? To what extent are learning curve maxima (plateaus) related to age, to sex, and to our own teaching methods?

Henry stated that positive and negative transfer and specificity of transfer need research as do the mental versus motor aspects of motor learning He further specified that laboratory investigation, with its potential for greater control, needs emphasis in areas requiring more precise definition and which lend themselves to finer evaluation

A review of the research on motor learning reported in the journals of psychology and the journals of physical education indicates little overlap in interest areas methods of approach, or goals

The psychologist seems concerned with motor learning primarily because it is an aspect of what appears at present to be the most significant and the most perplexing research area of human behavior—that of learning The physical educator is also vitally interested in motor learning because it forms the very heart of his subject matter that physical education is at least the adequate training and development of the body itself' (48,302)

The major emphasis of the psychologist is placed on the observation of a phenomenon, describing it, setting up conditions for its replication, then devising a system which summarizes integrates and explains the facts The

this sequence and emphasizes

explanation

(as reflected in his publications) appears to place greatest emphasis on fact finding, with of course considerable attention devoted to measuring devices including factor analysis Some of his research is brilliant but apparently not oriented or systematized with reference to theoretical considerations

There is one (perhaps distressing) feature which is apparent this is the seeming lack of awareness which the two disciplines have of the progress *and* problems in the other s area It is rather absurd to suppose that the methods of attack, of measurement, of analysis, of interpretation in the psychological laboratory, do not have some relevance (transfer if you will) to the physical education laboratory, and vice versa The attitude that there

is a dichotomy is expressed by Henry (29) Psychologists accept the specificity of transfer of motor skills, we do not, eventually we will have to change our concepts or show adequate evidence for retaining them"

Definition

Writers in psychology, education, and physical education rather consistently use the terms "verbal' and 'motor" learning in a way that would suggest to the casual reader that there were two kinds of learning—one kind involving thought or symbol manipulation, and the other, body S R association

At the two extremes, the dichotomy appears justifiable The simple conditioned reflex with synaptic connection in the spinal cord and overt body movement as effector, operating independently of influence from the higher neural centers, fulfills the requirements of 'learning definition, yet is quite distinct from verbal influence "Most of the research on conditioning, although usually treated as a field in itself, belongs properly under the heading of motor learning' (3,23)

Abstract symbolic manipulation, too, has its motor component (tension, subvocal speech, physiological changes in metabolism, etc) but this latter is at minimal level

It is generally held by psychologists that both verbal and motor learnings follow the same general laws and the phenomena of each may be explained by a single system

A notable exception to this point of view is held by Tolman, who suggests that there are at least six kinds of learning (1) cathexes, (2) equivalence beliefs, (3) field expectancies, (4) field cognition modes, (5) drive discriminations, and (6) motor patterns The first five are Gestalt oriented while motor patterns are S R (72)

Another justification for the use of the dichotomous terms is that some phenomena of learning show up better where verbal or motor reactions are studied For example, reminiscence (i e, the improvement of performance of incompletely learned material after an interval of time), though manifested in verbal material is shown to much better advantage in motor Therefore the phenomenon studied will suggest the medium of approach

It may be stated, then, that the use of terms 'verbal" and "motor" are justified on grounds of convenience just as Jung's 'introvert' and "extrovert' terms do not imply bimodality but merely points along a gradient, and that the psychology of motor learning is one with the psychology of learning

[2] Significance determined by attention given it by research workers

the salient and recent research in each area published in professional journals of psychology and physical education There will be no attempt to review the entire area of learning The material covered here is merely reflective as revealed by published research, of the areas of interest held by students of motor learning

The studies which have been done fall roughly into the following categories

- I Learning Theory
- II Measurement
- III Factors significant to motor learning
  - A Material learned
  - B The learner
  - C Method of presentation

LEARNING THEORY

The scientist is constantly attempting to discover relationships between operationally defined variables and to evolve a theoretical system which will make possible prediction of behavior over a wide range of conditions The more precise the prediction the more desirable the theory but the more vulnerable it is to empirical refutation

The learning theories of Thorndike, Guthrie, and Tolman are general [illegible]

[illegible]

which though widely attacked by psychologists resist explanation and systematization—distributed practice and reminiscence These two phenom[illegible]

[illegible]

areas throughout this paper

Briefly, Hull's Performance Inhibition Theory suggests that both massed and distributed practice yield an inhibitory potential (IR) which reduces the work output of the organism IR, developed during unspaced practice, is composed of 'reactive inhibition' and "conditioned inhibition' (SIR),

* For a detailed statement of these positions the reader is referred to (12 51 67)

but distributed practice yields less inhibition hence is more efficient in learning (35)

Modifications or extensions of the theory are necessary to account for such phenomena as reminiscence (39 40,41)

Hull's prediction that IR and SIR contribute equally to the total inhibitory potential was tested by reviewing existing motor learning studies The results of the studies supported the prediction if allowance for 'warm up" was made (6)

Kimble's modification of Hull's Performance Inhibition Theory was found adequate in the explanation of certain characteristics of the motor learning curve not explained by other existing theories (78)

Several recent attempts at evolving theories of motor learning to explain specific phenomena have been made For example, an attempt to explain the phenomenon of reminiscence was made by Amons in 1947 (2) The purpose of the study was to develop a theory of motor learning directed primarily toward incorporating reminiscence and spaced phenomena in a single system The technique involved making assumptions derived through analysis of certain characteristics of rotary pursuit performance curves

MEASUREMENT OF MOTOR LEARNING

Any field has difficulty measuring factors which are not operationally defined In physical education, for example, the early literature is found to include such terms as "motor ability,' physical capacity," "athletic ability," "motor capacity," "physical skill, 'motor educability,' in a rather indiscriminate manner Reliability and validity, too, have variant definitions Reliability of scoring refers to the consistency with which a test has been scored, i e, R = Score I r Score II Test reliability refers to the consistency of performance on a test This statistic may be found, for example, by the test retest method, by administration of two forms of the same test, or by split halves, but in general the reliability of a test is a variation of R = Test $_{I}$ r Test $_{II}$

Validity is a measure of the relationship between the measuring and its criterion (V = Test score r Criterion) The choice of the criterion presents the problem

A valuable tool to correct this condition and to give real meaning to testing is by the use of factor analysis This process is used to reduce to a few common factors the findings of many measurements and is a refinement which makes it possible to ascertain what is being measured and gives in quantifiable terms an operational definition of variables under analysis Research workers in physical education have done considerable work using this device—under the leadership of C H McCloy (49)

The recent research in measurement of motor learning for convenience may be categorized as follows

1 Statistical analysis of existing tests
2 New measures of motor learning
3 Prediction of performance
4 Factor analysis
5 Measuring devices to examine theoretical constructs

STATISTICAL ANALYSIS OF EXISTING TESTS

Two articles demonstrate the difficulties to be found in ascertaining reliability and validity The reliability of a modification of the Humiston Motor Ability Test was determined by four trial administrations and was found high The validity was derived by correlating with a battery of athletic skill tests and with participation in extracurricular activities The significance of studies of this type hinge on the choice of "criteria," i e, the meaning of validity (38)

The method of scoring (eight methods were tried) was found to be significant in the measurement of improvement on a specific motor skill (50)

Using one hundred elementary school subjects, Smith found that many of the existing measures of motor ability differentiated significantly fast and slow learners of two motor learning tasks (64)

FACTOR ANALYSIS

Factor analysis a statistical technique which analyzes in simplest terms the constituency of complex measurement, was applied to many tests of improvement (20)

Tests of motor ability, athletic ability, strength, speed, power, agility, and endurance were factor analyzed with 100 high school girls as subjects—4 general factors were isolated and 4 specific factors of motor learning were identified (38)

Sixteen factors were obtained from intercorrelations between printed tests and motor learning situations but appeared to be in general specific to the situation (57)

Factor analysis applied to arm hand precision tests identified three specific factors (62)

1 Steadiness and precision involving spatial components in two or more planes
2 Precision of movement in a restricted plane
3 Involuntary movement of hand or arm

Ten basic factors involved in motor ability were identified from forty performance tests administered to one hundred Air Force recruits The 40 performance tests included pursuit rotor, reaction time, balance, etc (24)

New Measures of Motor Learning

A psychomotor scale for children intended to measure manual ability as expressed by five psychomotor components was adopted to American standards from the European New norms were derived (76)

A maturational scale of motor ability was presented in the Vineland adoption of the Osertsky tests (14)

'Dynamic balance' purportedly reflecting present status of motor abilities was measured by a test which required the subject to walk, balanced on beams which became progressively narrower as the test became more eliminative Standardized techniques made possible a highly reliable scoring procedure Standardized norms were derived, using a wide range of school age children (59)

Prediction of Performance

When two factors are interrelated, a regression equation may be derived which will make possible prediction (with error determined by variability in the two factors, size of sample, and the degree of relationship between them) of one from the other

All the measuring devices can predict the criterion if their validity has been determined—but some use face validity, which precludes accurate prediction of a specific behavior A test purporting to measure 'balance,' for example, can predict performance in another activity if the relationship between the other activity and balance as measured by that test has been determined

Complex coordination tasks were predicted better by initial performance on the task than printed tests of simple psychomotor tests Or, the whole task was a better prediction of itself than an analysis of the potentialities making up that whole (1,77) The problem of specificity is concerned here

Henry found that jump, speed of arm movement and balance were valid measures of motor educability in a study where the initial skill of the subjects was made a constant by statistical means (30)

New Measuring Devices to Examine Theoretical Constructs

Several new devices were developed and analyzed to measure specific problems of both theoretical and practical nature Reference is made to a few (23,45,80)

FACTORS SIGNIFICANT TO MOTOR LEARNING

In general there are three variables to be considered in the learning of motor skills (1) the material learned, (2) the learner, (3) the mode of presentation of the material to be learned These categories are for conven-

ience of classification only and cannot realistically be dissociated We consider meaningfulness of motor learning, for example, as a characteristic of the material learned and find it affected by the mode of presentation and by characteristics of the learner

Despite the limitations of this classification, a brief survey of these three areas follows

Characteristics of the Material Learned

In learning material predominantly of a verbal nature there is considerable variability qualitatively and quantitatively within the task itself The material may, for example, be meaningful or nonmeaningful, familiar or new, short or long the composite parts connected or nonconnected, etc The efficiency of perceptual motor learning, too, is modified by certain characteristics of the material learned but to a lesser degree than material predominantly verbal

A characteristic of the material to be learned is meaningfulness In verbal material this can readily be illustrated in three degrees of meaningfulness (1) nonsense syllables, (2) a series of nonrelated words, and (3) a sentence Meaningfulness' in motor learning could be defined from different viewpoints an individual learns a certain skill because he sees its importance to some phase of his adjustment therefore it has meaning to him A

arrange sequence, bring to consciousness cues which are significant to learning, etc

The amount of verbal explanation was found to be positively related to the efficient learning of a motor skill which in this particular experiment was the assembling of a mechanical puzzle (68)

Verbal instructions were found helpful in learning of simple motor tasks

sideration in that

study of particular problems In the study of specificity and generality, for example, dart throwing as a test of motor skill could not be adapted to the requirements of the research design because of low individual difference reliability in the learning scores Balance on the stabilometer, caroming a light ball from a flat surface to strike a wall target, and the Lambert motor learning test appear not to have this inadequacy (56)

Characteristics of Learners

Previous Experience Transfer may be found ... the learning of one

old response to a new situation, or an inhibitory (negative)—the learning of a new response to an old situation

Transfer was first explored objectively by James (36) and later by Thorndike and Woodworth (71) in experiments which disproved the prevailing "faculty" theory

The significance of transfer is seen in the fact that practically all learning of a verbal and motor nature is influenced by transfer

THEORIES OF MOTOR LEARNING

Theory of formal discipline According to this early theory the mind had powers or "faculties" which, like a muscle, could be strengthened through exercise Practice in reasoning, for example would assist the individual to solve in later life any problems involving reasoning The memory, too, could be trained through exercise, i e, memorizing long and difficult material Until recently transfer from one motor learning to another was thought to follow the same general principles, i e, generality of transfer was widely accepted, but the results of recent research indicate that the concept of generality of motor transfer is as fallacious as generality of verbal learning

Theory of identical elements According to this theory advanced by Thorndike (70) transfer from one situation to another depends upon the elements of content, attitude, method, or aim common to the two situations A person who typed term papers could also be expected to type stencils since the same skill is involved, but would be able to transfer this skill to playing the piano only to the degree that piano playing is identical with typing

Theory of generalization The ability to apply to varying situations the principles and meanings derived from specific experience demonstrates

ence, which modifies the problem solving techniques in other similar situations

A large amount of research on both positive and negative transfer of motor learning has been reported in the past few years Negative transfer has been studied in relation to operation of controls of aircraft where the pilot would learn one set of responses to fit a situation then have to unlearn it and relearn another Positive transfer was utilized by flight instructors to reduce the hazards of actual flying by actually learning to fly in a trainer while on the ground

A brief resume of specific studies follows Considerable research has been done in which the relationship between transfer and task difficulty was investigated Battig for example found that positive transfer from verbal pretraining to motor performance consistently decreased as motor task complexity increased (8) For a summarization and critical evaluation of recent studies on the relationship between transfer and task difficulty the reader is referred to (19)

In another research preliminary training with a pictured representation of a task was found to be effective in learning a motor skill requiring different manual responses to lights varying in color and position (26)

In a study of 47 high school students there was no transfer from activities of table tennis regular physical education or special arm exercises to efficiency of coordination in coordinated muscular movements (47)

It is suggested that the decremental effect of massed practice (see discussion of massed and distributed practice) actually transfers to response systems other than those exercised This finding was made in a study of 2 groups of 15 subjects each Group I practiced with the nonpreferred hand had a 5 minute rest period then practiced 30 trials with the preferred hand Group II was given the same treatment without the five minute rest period Group II was found to be inferior with the preferred hand which indicates that the effects of massed practice transfer (42)

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Though considerable work on proactive and retroactive inhibition and facilitation has been done in verbal lea n ng l ttl [illegible]
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terference
the learning or motor skills are reported (25 46 55)

An interesting evidence of transfer is found in a comparison of mental practice and physical practice in learning a motor skill Physical practice was demonstrated to be superior but mental practice was found better than no practice at all (74) However hypnotically induced 'hallucinated practice illicited no improvement (16)

PHYSIOLOGICAL STATE

The term physiological state is used here to include the internal environment of the learner and to note any relationship between motor learning and this environment

Considerable research has been reported on the effects of various drugs on behavior but little on the effects on motor learning

It has been found in general that drugs of a depressant nature retard the rate of conditioning but accelerate the rate of extinction while stimulants have the opposite effect on both acquisition and extinction of the conditioned reaction (32 119–120)

Significant to motor learning are studies concerned with the effects of drugs on fatigue Fatigue in most experiments is measured in part by motor performance hence is relevant to the learning of motor tasks

An early study evaluating the effect of caffeine on behavior revealed that caffeine increased the rate of tapping and improved the accuracy of typing A small amount was found to increase the speed of typing while a large amount tended to reduce speed All doses were found to increase hand tremor ([illegible])

The effect of sleep deprivation on motor performance and the fatigue countering effects of benzedrine and barbiturates were studied (75) Tests of balance reaction time steadiness and marksmanship together with other tests were administered to a large number of men over an extended period Benzedrine prevented fatigue at the 36 to 48 hour level of wakefulness but barbiturates (amytol and V 12 ethyl B methylallyl) showed little effect over the first 48 hours Schizoid behavior and other psychological disturbances were noted in numerous cases but the subject s behavior returned to normal after a period of sleep

The fatigue reducing effects of benzedrine are supported in other studies (13)

The *effects on psychomotor performance* (pursuit steadiness tapping rate) of exposure to hypoxia high altitude and hyperventilation were studied It was found that the level of performance was reduced for altitudes over 18 000 feet only because of oxygen deficiency Supplemental oxygen even at 35 000 feet brought motor performance back to normal (59)

INDIVIDUAL AND GROUP CHARACTERISTICS

The individual and group differences significant to motor learning have received considerable attention by research workers The variables considered here are intelligence (education) age sex and race The relationship between personality factors and motor learning in individuals and groups has been little explored up to the present time although it appears a fruitful area of study

There has however been relatively little research in either psychology or

AGE

Age, *per se* is significant only in so far as it is associated with increment and decrement of the physiological and psychological bases of learning

A review of the research on learning as a function of age concludes in general that the ability to learn is present before birth (e g, simple conditioning as demonstrated by Marquis) and increases with age through the first two decades of life (51,535) This latter, however, is not supported by Munn who interprets the research as indicating that improvement from practice is not directly related to age (53)

The ability to learn motor tasks appears to decline from maturity to old age as is shown comparing young subjects with old in learning to perform a coordinated movement by direct vision and mirror vision (58)

Recent research on motor learning would tend to support Munn s position, for it was found that the amount of learning to a considerable extent and the rate of learning to some extent favored 10-year old boys over 15 year-old (31)

SEX

The general conclusion regarding the differences between the two sexes in ability to learn is that innate differences may be present but research has yet to dissociate their effects from those of learning Manifest differences may be attributed to factors of physique (size and strength) and to differences in motivation and experience, culture, etc Positive transfer may contribute to these differences The suggestion that no biological difference exists is demonstrated in studies which report an initial motor superiority of boys which is reduced to insignificance by practice

A longitudinal and cross sectional study of boys and girls showed that motor coordination as measured by the Brace tests followed a pattern of development in boys similar to growth in standing height Girls showed little change after the thirteenth year (22)

A study investigating the effects of training in ball throwing of young children showed the superiority of boys over girls and the increase in ability as age increased (21)

INTELLIGENCE

In general research findings consistently indicate a low but rather positive relationship between intelligence and motor learning These correlations however, range from 10 to 70 They present too a significant problem in semantics

[illegible] ucial here Porteus and others used

[illegible] gence and motor learning is reported as

over 70 where "intelligence" is measured by the Otis Gamma and motor learning by a finger maze (67)

Another study noted the superiority of college men on the Minnesota Rate of Manipulation Test to the population norms It was hypothesized that motivation, not intelligence or social competition was the significant factor (61)

A study designed to evaluate the qualitative and quantitative differences between college students and mental defectives revealed that college students were superior and that both groups showed better results using distributed practice over massed (10)

Race There is no definitive research which indicates real differences in motor learning ability between so called "races' Little recent research has been devoted to this (15,28)

One study showed that Negro children were superior to white norms in gross motor development Although this factor may be significant to motor learning it probably is not a function of race but of the degree of permissiveness associated with homes of lower socioeconomic status (79)

CHARACTERISTICS OF PRESENTATION OF PERCEPTUAL MATERIAL

MEDIA

stimula
learning
of more
than one medium is apparently superior in general to a single medium because of this facilitation The mode by which the stimulus is presented probably has little significance in learning (51,484–485)

The method of presentation of perceptual motor material, however, appears significant in learning efficiency as found in maze learning where finger contact was superior to stylus contact, yielding probably greater information

Visual cues were found superior to verbal and verbal superior to kinesthetic in learning a lever positioning habit (7)

Training films were found effective in the learning of knot tying under the following circumstances (81)

1 Verbal description was present but not detailed to a point where it con
r

2 active were
third person
passive was least effective

3 Sound ahead of the picture was superior to sound after it

Film demonstration of motor skills was found almost equal as a teaching device to actual demonstration and coaching (27)

When 'live" and "film "taught groups were compared on the Metheny Motor Skills Test, the "live-"taught were significantly superior to the "film taught The projection methods and film loops were found better than nothing (53)

DISTRIBUTED PRACTICE

Distributed practice has generally been found more effective than massed practice in learning motor skills The amount of superiority, however, apparently varies with the individuals involved, with the specific motor task, and with the variation of practice times constituting the "distribution" of practice

Several hypotheses have been tendered to explain the research findings concerned with distributed practice (51,171–193). In general, distributed practice enhances learning under a wide range of conditions but no single hypothesis adequately explains this finding possibly because it is founded on no single set of conditions

Phenomena resulting from variously distributed practice in studies of motor learning are best accounted for by reactive inhibition (51,189,34)

A typical study comparing distributed and massed practice was made in which two groups of subjects equal in significant respects practiced a pursuit rotor task One group (distributed practice) received 30 15 second trials per day for 2 days with a 45 second rest period between each trial and a 5 minute rest period at the end of each 6 trials The other group (massed practice) also received 30 15 second trials a day for 2 days but had no interval between trials and only the 5 minute rest period after each 6 trials Results indicated the consistent superiority of distributed over massed practice (5)

Two studies show that the introduction of brief rest periods is particularly beneficial at the onset of motor learning (9,65)

It has also been found that, in general, but considerably dependent upon the particular task, longer rest periods must accompany longer periods of practice for optimum learning (73)

Bilateral transfer of the negative effects of massed practice has been previously discussed in this chapter

A considerable number of other research articles on distributed practice in motor learning were published in recent years in journals of psychology

WHOLE PART LEARNING

A summary of studies of motor learning concerned with whole and part methods of presentation indicates that the whole method of learning is better for subjects who are more "intelligent," are more mature, and are

more practiced in whole learning For practical purposes a combination of whole practice with repetition of difficult parts apparently increases efficiency for both verbal and motor learning

The definition of 'intelligence here is significant Intelligence to learn material of a perceptual motor nature, i e, motor educability, would best predict performance using the whole method in the learning of motor skills Academic intelligence, however, has been found associated with the learning of motor skills as previously discussed The whole method of learning rifle marksmanship (slowfire) was found superior to the part method but the whole method was not superior to the part method in sustained fire except for subjects of superior intelligence (52)

Another question of definition arises what size should the whole' be? This apparently is an individual problem A person of higher intelligence or motor educability would be able to master an intricate dance step better than a person of lower aptitude Quite possibly a complete routine would constitute a whole for the former while the latter would consider the routine a composite of wholes and learn them separately Putting these together into a meaningful pattern, however, is a time consuming and difficult task Of course, some tasks would be broken up into meaningful wholes by even the most skilled

Th[illegible]

[illegible]entation, two conditions of stimulus presentation in learning a perceptual motor task were compared In the first condition the subjects were given a total amount of time with a number of tasks to perform In the second condition they were presented with the tasks individually and forced to react within a restricted time limit The over all result indicated a significant superiority of the second condition (17)

Little recent research has been reported on whole part learning in physical education settings The conclusions of the older studies (18,62) and the more recent (43) are in general that the whole method is superior to the part methods of presentation

In the recent study the whole method was compared with the "whole direct repetitive method" Each part was demonstrated, described, demonstrated, then practiced to the criterion in teaching basic gymnastics and tumbling stunts to male college students In general, no statistically significant over all difference in learning was manifested between the two methods

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JOHN H SHAW AND
HAROLD J CORDTS

Athletic Participation and Academic Performance

SUMMARY

A survey of the literature on the relationship of athletic participation to academic performance yields conflicting and inconclusive results There are just about as many authors who conclude that athletes are academically superior to nonathletes as there are who believe there is no difference or that nonathletes are superior Although almost no research has been concerned with the possible relationship of physical fitness and academic performance what has been done suggests that a positive relationship may exist

Most of the available research on the subject has been summarized by Jacobsen (24), Cooper and Davis (8), Kyle (30), Kissell (28), Kremer (29), and Ranck (35)

Many of the studies on this subject are inadequately controlled or incomplete in their coverage and often the conclusions reached are based on per

Among the shortcomings of the research reviewed were lack of uniformity in procedure, inconsistency in terminology (particularly in the definition of an athlete), inadequate equation of groups, inadequate samples, relative short time span of the studies, and the use of teachers marks, which are notoriously highly unreliable as the only basis for interpreting academic performance

In undertaking further research on the subject of the relationship of exercise and/or sport participation to academic performance, it is suggested that samples should be carefully chosen and equated by chronological age, year in school, intelligence quotient, and course of study Academic achievement

should be checked over a three or four year span of time, preferably by two valid academic achievement tests of high reliability Teachers' grades might also be used for comparative purposes

Some studies should be removed entirely from the realm of organized athletics in order to more nearly measure the effects of physical activity alone on academic performance rather than activity plus other things involved in athletic competition *A more dichotomous sample might be employed in some studies representing a relatively active group physically and a relatively inactive group physically, both of which are otherwise equated Without doubt, the recent renewed emphasis on physical fitness should stimulate additional research on the relationship between fitness* per se *and academic success*

Since relatively few studies involving girls have been reported, more studies with such a sample would be worth while

As very little research on the effect of exercise and/or sport participation on academic achievement has been attempted in the past 10 years a few

The effect of participation in sports on the academic performance of students has been the subject of many articles and research studies These efforts vary from a mere reporting of personal opinions or random observations in a limited situation to a few fairly well conceived and carefully conducted research projects

Although coaches and physical education teachers are particularly concerned with this question, many teachers of other subjects as well as administrators are equally concerned, as evidenced by the literature available

SURVEY AND INTERPRETATION OF THE LITERATURE

About half of the material available on the subject of sports in relation to academic performance is in the form of master's theses, and the remainder represent special projects, resumes, and a few doctoral dissertations Since the population in most studies was composed of either high school or college students, it seems logical to consider the studies under these two categories

Studies Involving High School Students

A survey of the literature on the effect of sports on academic achievement, using high school groups as a population, shows no clear-cut conclusions one way or the other There seems to be about as much evidence on one side of the question as on the other

Studies Indicating Academic Performance of High School Athletes to Be Superior to Nonathletes The following studies are representative of those indicating that sports participation is favorable to academic achievement

Angus (2 83) found that the physical efficiency of the athlete promotes a better chance of attaining high scholarship, and that while the nonathletes in some instances attain a higher scholastic standing, they probably could achieve much better standing if their physical efficiency approached that of the athlete He further indicates that the difference in scholastic standing slightly favors the athlete He would therefore advocate encouragement of participation as a spur to scholarship Scholastic achievement was based upon grades attained by 79 athletes and 310 nonathletes

Blum (5 8) found that on the basis of Otis Test scores and semester grade average, intramural competitors were as a group significantly superior to noncompetitors in the same grade In surveying personal records in Manley High School in Chicago, he also found that intramural competitors as a group were significantly superior in scholarship

Ray (36,141) reports that a study of 432 boys in Palo Alto High School indicates that physical activity, without consideration of athletic participation, is definitely beneficial both to health as indicated by height and weight in relation to age, and to achievement, both academic and physical Mental ability and achievement were measured through use of the Terman Group Test and academic grades, while measurements of physical ability and achievement were obtained by use of a specially devised decathlon in which skills were tested that were fundamental to the Palo Alto activity program He found the athlete superior in mental ability, as measured by intelligence, and more superior as measured by academic averages However, as in many other studies reviewed, the statistical significance of the findings was not indicated

Kremer (29,14) in a particularly carefully conducted five year study concluded that athletes exceeded nonathletes scholastically by over one third [illegible] grades of athletes and nonathletes in either colleges or large secondary schools

Studies Indicating Academic Performance of High School Athletes to Be Inferior to Nonathletes At least 10 studies reviewed indicate that the academic performance of athletes is inferior to that of nonathletes Ryan (40,155) and Cooper and Davis (8,70) summarize the findings of a number of studies which give the nonathlete some advantage over the athlete academically Cormany (9,460) and Eubanks (12,36) reach the same conclusion

Fenniman (13,4), in one of the few studies involving girls, defined her athletes as girls participating in a major sport and in the upper quartile of

her physical education class, whereas a nonathlete was a girl not participating in a major sport and in the lower quartile of her physical education class The physical education rating was given by the physical education instructor on the basis of a proficiency rating in athletes The grade levels included in the study were three through six She concluded (13,28) there were 96 8 chances in 100 that nonathletes would on the average score above the athlete, or that the true difference between mean scores of the two groups is somewhat greater than zero in favor of the nonathletes Limitations of the study include small size of sample (44 pupils), grade level of the subjects, and the fact that the mean I Q of the nonathletic group was 118 while that of the athletic group was only 107 8

Reals and Reess (37,534) in a well-controlled study claim to have found a substantial difference in favor of the nonathlete However analysis of their data seems to indicate this is an overstatement of the case

Studies Indicating No Difference in Academic Performance Between High School Athletes and Nonathletes Approximately as many studies of high school students tend to reflect no difference in academic performance between athletes and nonathletes as support an advantage for one group or the other Some of the studies reaching this conclusion are those conducted by Nelson (33,4), Allen (1,36), and Snyder (43,14) Rhodes (39,38), who reached the same conclusion, makes the interesting observation that athletes of superior mental ability seem to achieve less scholastically than do non

ty appear

o studies

twenty five studies, or 35 72 percent, indicate equal scholarship, and the remaining fifteen, or 21 43 percent, indicate that the scholarship of athletes is below that of nonathletes

Studies Involving College Students

Because of selective factors and economic pressures sometimes associated with college athletics, it might be expected that the high school and college situations would be quite different However, such is apparently not the case Findings of studies involving college and university students tend to follow the same general pattern as those involving high school students Excellent reviews of the literature in this area were completed in 1927 and 1929 by the Carnegie Foundation for the Advancement of Teaching (41, 42), in 1931 by Jacobsen (24), in 1934 by Cooper and Davis (8), and in 1936 by Kissell (28)

Ryan (40,154), reports that Finlay found athletes' grades averaged 65 90 percent, nonathletes averaged 64 87 percent, but that football players averaged 62 90 percent This study would indicate that perhaps research on the effect of participation in a particular sport on academic performance would be more rewarding than studying the effect of athletics generally

Hackensmith and Miller (19 99) at the University of Kentucky, and Washke at Oregon (47,27) conclude that intramural participants have a slightly higher mean academic grade than either varsity athletes or non participants

At Smith College, Somers (44 90) found that women students in the upper 9 percent of the class who participated in class team competition were slightly superior in academic average to the nonparticipants

Cooper and Davis (8,71) reviewed a number of studies, several of which indicate athletes have a higher scholastic average than the average of all men students Since the athletes are a select group, it would not be unreasonable to expect some superiority and therefore the comparability of the two groups might be open to some question

Studies Indicating Academic Performance of College Athletes to Be Inferior to Nonathletes Frequently referred to by writers in this area is the work of Savage which is found in the *Twenty second Annual Report of the* 1 for

lete in 9 out of 10 semesters

Glickman (16,44) compared 110 athletes with the entire male student body of 2500 at Brooklyn College and concluded on the whole that grades of all athletes reveal lower scholarship status than the grades of the non athletes They receive more marks of 'C' or C– ' and their grades show a stronger tendency to gravitate toward the passing line

study

In 1939, Hutchinson (23,3) found at Kansas State Teachers' College that nonathletes had slightly higher scholastic achievement than athletes, and furthermore nonathletes demonstrated the most consistency in their scholastic achievement over a four year period 1 at the

and universities and concludes that there exists little difference in the scholarship of athletes and nonathletes, although there is a slight advantage in favor of the nonathlete One of the most interesting of his observations is that nine different definitions of an athlete were used in these studies, the most popular being a boy who was awarded a varsity letter or numeral Many studies failed to indicate the method used to determine the definition of an athlete

Studies Indicating No Difference in Academic Performance Between College Athletes and Nonathletes The following are examples of studies reporting no difference in academic performance between athletes and nonathletes

For the combined school year, Griffith (18 55) concluded that no difference existed in the scholarship of athletes and nonathletes in a study of 400 athletes and 666 nonathletes who were freshmen at the University of Colorado Purdom (34,32) finds varsity athletes have the same grade point average as the entire student body although slightly superior to all men students

Eubank (11,16), in an interesting study, indicates no significant difference in average scholastic standings of lettermen and those of other college students He also points out the marked relationship between high school and college scholastic attainment, as well as the positive relationship between high school and college scholastic attainment and football playing success

Tuttle and Beebee (46,180), Summers (45,48) and Belk (4,25) all present corroborating evidence that athletes and nonathletes are approximately equal in scholastic attainment

Cooper and Davis (8) review eight studies conducted between 1915 and 1929, which report no difference in the academic achievement of athletes and nonathletes Their studies include small and large samples from various

year at the State University of Iowa On the other hand, Appleton (3) found no significant relationship between physical ability upon entrance and academic success as measured by academic grades at West Point However, he did find a high positive relationship existing at the lower extreme of the physical ability range, between entrance physical ability and the ability to graduate from West Point

Summary of College Studies The evidence presented by various studies on the academic achievement of college athletes as compared with non athletes is conflicting and about evenly divided between studies indicating athletes are better scholars, athletes are the equal of other students scholastically, and to a somewhat lesser extent that athletes are inferior to the general student body in scholarship There is some evidence of a relationship between academic success and physical fitness, but this relationship is far from firmly established

LIMITATIONS OF KNOWLEDGE AND SUGGESTIONS FOR FURTHER RESEARCH

Although there has been a great deal written concerning the effect of athletics on scholastic standing, much of it is based on personal opinion or mere observation in limited situations and must be discounted by an objective evaluator Prior to 1930 few if any of the studies were treated statistically Jacobsen (24,384) noted this fact along with other shortcomings in reviewing 17 studies completed between 1910–1929

Even in instances where statistical techniques have been used, many authors fail to include enough information to interpret what is given so that it would be of practical significance to the reader

It is not surprising that the best that can be said for the existing studies is that their findings are conflicting and inconclusive Their lack of agreement can be largely attributed to an extreme variety of methods in attacking the problem Lack of uniformity ı

A serious weakness in many of the studies was inadequate equation of the groups Many compared a small number of athletes with the remainder of the student body which might run into several hundreds or thousands Groups studied varied extremely in kind and size Some studies obviously utilized inadequate samples In several instances, as few as 10 or 15 cases were included in the total sample Very few studies of this subject have involved girls

Some studies have suffered because they did not take into account performance over a span of years Indeed, many were limited to a single year

Studies such as that of Savage (41) which compared achievement over several years would appear to hold greater promise for conclusive information

With the exception of the work of Cooper (7), Reals and Reess (37) and Rhodes (39), one of the major weaknesses in existing studies lies in the subjectivity involved in interpreting academic performance on the basis of teacher's marks which are admittedly highly unreliable It must be noted that all too few authors indicated the limitations of their work

Inevitably there are several variables which are difficult to control when undertaking a study on the subject of this chapter Therefore it seems reasonable to assume that a study of a particular institution would be most valuable locally but of little significance for any great length of time, or for another institution In undertaking such studies a sample of reasonable size (perhaps 100 for each group) might be equated by chronological age, year in school, intelligence quotient, and course of study Academic performance should be checked over a span of three or four year s time on the basis of two valid academic achievement tests of high reliability Teacher s grades might also be used for comparative purposes

In addition to the above suggestions it might be helpful to remove some studies entirely from the realm of organized athletics with its heavy demand upon the time and energy of the participants and its possible preferential treatment of athletes in terms of special tutoring, carefully chosen courses and professors, and possible preferential grading Studies along these lines might reasonably be expected to shed light upon the effects of physical activity rather than activity *plus other things involved in athletic competition* It is not surprising that in the past most studies have been concerned with athletics, but we need more studies like that of Ray (36) which are concerned with the relationship of physical activity *per se* and its effect on academic achievement It is the belief of the authors that studies of this [illegible]

[illegible]

the other Differences, if they do exist, might show up more clearly in such a research

Furthermore, it is suggested that some studies involving athletes should be undertaken with samples restricted to particular sports Probably the effect of football on academic performance, because of relatively intense periods of training for several hours daily, would have a different effect than [illegible]

by Bell (4), Ferguson (14) and Jordan (27), little has been done in this area in the past 10 years A few carefully conducted studies along the above

suggested lines might therefore be invaluable in helping to answer the question of the effect of exercise and sports participation on academic achievement

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PART V

Cultural and Historical Aspects of Sports and Physical Education

32 FLORENCE STUMPF FREDERICKSON

Sports and the Cultures of Man

SUMMARY

In this discussion emphasis is placed upon the importance of the study of sports in the cultures of man, for the following reasons (1) to broaden the perspective of the common ethnocentric attitude, (2) to fill a gap in the kinds of research being undertaken, (3) to promote a deeper understanding of variations in cultural definitions of work and play, and (4) to seek an understanding of causes, effects and social controls in the sports scene

Illustrations are given from the literature of cultural and social anthropology For example, the ancient sport of wrestling is shown to have per [illegible] *) a legal and* [illegible] *, (2) a part of* [illegible] *(4) a demonstration of prestige and power, and (5) a means of insuring a successful harvest*

In order to lend perspective to an examination of the meaning of sports in our own culture, spectator behavior in other cultures is considered, and the ritualistic function of sports is taken into account as a cultural phenomenon

Although the literature dealing with the relationship of sports and culture is limited, there is a growing awareness of the importance of this subject, and it provides a rich field for research by properly qualified persons

In all human societies, rituals, festivals, dances, music, pictorial art, sports and games, not only give pleasure but in addition provide outlets for creativity and reinforce the group identity and solidarity Such activities also tie closely into social, religious, economic, and other phases of life (28) The preceding statements have been amply documented by the research and

writings of anthropologists, ethnologists, sociologists, historians, travelers, missionaries, and others Yet only a small part of this wealth of material has been subjected to study, analysis, and synthesis by research workers

Important as all the basic questions are which remain to be solved through the scientific work yet to be done in physiology, anatomy, kinesiology, psychology and related fields, their importance in no way overshadows the value of the understandings to be sought in cultural research In fact the multiplicity of public and practical problems into which culture enters as a consideration and to which our past culture makes us heir, are obviously at least as important and as pressing as the problems that are touched by our biological physiques, natures and evolutionary rooting (30)

Whether or not the cultural approach properly belongs in the category of science is still being debated in many quarters For example, one expert has expressed the opinion that the science of man viewed naturally and culturally, individually and collectively, biogenetically and historically, is an incoherent conglomerate of mutually incompatible theories" (51), whereas another expert has argued that behind the apparent lawlessness of social phenomena there is a regularity of configuration and tendency which is just as real as the regularity of physical processes in a mechanical world, though it is a regularity of infinitely less apparent rigidity and of another mode of apprehension on our part (44) Nevertheless, the pursuit of knowledge which leads to greater understanding is undeniably worthwhile and rewarding whether or not the particular methods or results qualify under a rigid definition of science

which individuals set up purely artificial obstacles and get satisfaction from overcoming them (32) We wish to differentiate at this point between sports as a cultural pattern[1] and the spontaneous activities and random interests of the young child at play—whether running about, jumping, building huts, or throwing objects Both sorts of activities may originate from the

ture of courting, mating, marriage, procreation, divorce, and perversions that have eventuated from the sex drive' in man The stark statement that

[1] One explanation of the scarc ... rature in the cultural aspects of sport ... ave been so intently focused on the ... riculum rather than sports as a cultural

man must eat reveals nothing of the cultural patterns of food gathering growing, distribution, and consumption that stem from this simple fact The same thing is true of the play impulse and its failure to explain in itself the manifold forms of games, sports, and contests and their attendant cultural paraphernalia

Whether at any given time in history man plays for fun and self expression, for prestige, power, and glory, for financial gain or political advantage, his motivations are to a large degree culturally determined Whether or not sports hold a place of esteem as an expression of national pride and strength, as a respected instrumentality for propitiating the deities or upholding the honor of the tribe or the nation, or as an accepted means of educating the youth—these things are culturally determined Whether participation brings respect and reward, or disdain and disgrace, depends on the cultural climate in which it takes place

The cultural role of sports in our present day society is little understood Over the period of the major part of our existence as a nation, recreation for its own sake has not been a value widely held in American culture, the em phasis has always been on work There were always play and recreations, of course, even in our early history But often these were rationalized in work terms—the barn raisings, the house warmings, the corn husking contests Even the pleasures of hunting and fishing were rationalized as contributing

or entirely acceptable for adult men and women to go forth with golf clubs, tennis rackets, fishing reels, skis, or what have you and have no other reason than the pursuit of pleasure (14)

This trend in our culture seems to be the result of more than a lessening

and during leisure (43) Research in communication and public opinion supplies further evi ... changing cultural pattern In the realm of popular biography ... reading about the idols of production

An understanding of the current cultural definitions of work and play in American culture would seem to be a basic requirement for all those con cerned with the administration of sports and physical education, as a prereq uisite to policy making, programming, and action

Expansion in cultural research will mean that the profession and its students will no longer limit their study and investigations almost exclusively to the past or present achievements of their own country and Western European society but bring an enlarged vision and a widened tolerance of societies modeled on plans entirely different from their own motivated by ideals that are never without justification no matter how crude or extraordinary they may seem (6) A significant trend in current history is the acceleration of culture contact and culture change which is going on all over the globe No nation plays a more central role in the process than the United States One item in this total picture of culture change and culture contact is sports and the attendant complex of ideas concerned with physical fitness

One of the prime values of science has always been acknowledged to be in its predictive function Prediction in the matter of human behavior could not proceed along very successful lines so long as it was based on the naive assumption of a homogeneous human nature The assumption within this framework was that all human thinking proceeds from the same premises that all human beings are motivated by the same needs and goals As Murphy puts it (40) it was the repudiation of the concept of human nature everywhere the same which led to the riches of cultural anthropology In the cultural framework the thought processes are understood to emerge from radically different premises especially unconscious or unstated premises Utilizing the concept of culture the research worker will attempt to look beneath the surface and bring the culturally determined premises into the light (31)

Sport is primarily a cultural product and must be understood as such, even though its incidence and formal development rest on considerations of a biological and psychological nature Research is thus concerned with the problem of seeing sports and sports history in the larger framework of human behavior in the individual and in society

WHY CULTURAL RESEARCH?

The most cogent explanation of the need for a cultural study of sports lies in the fact that there is no relation of simple function between specific organic needs rooted in the body and mind of man or in his environment and his cultural activities Although organic factors are always present and operative, another set of factors intervenes between the impulse and the act These are the factors represented in the ideas beliefs and practices of the particular culture of which the individual is a part (30) Cultural research in sports is pointed toward a clearer understanding of the degree to which cultural living has blocked modified encouraged or redirected the energies that are operative primarily at an animal level (40)

One of the chief attractions of this field of research lies in the fact that

most of the work is yet to be done and most of the questions remain to be answered To recognize and describe classes of phenomena is a legitimate aim of scientific inquiry Yet as Staley has pointed out, this has not been done for sports within our own culture, let alone the cultures of others, past and present Although the American people are currently participating in more than 250 sports, there is available in the literature historical accounts for something less than 50 of the lot, and as Staley has further pointed out, most of those are out-of date, and/or unreliable and/or sketchy in character (46)

Lacking classification, data are merely gathered facts They must be organized according to some scheme or they are not susceptible of systematic treatment Therefore schemes of classification vary in accordance with the problem that is being analyzed, and classification thus becomes an essential first step toward analysis (20)

At this point we take the liberty of paraphrasing the words of Herskovits (24) in his discussion of classification and process in the study of culture Categories of classification of sport with which we are familiar (competitive, noncompetitive, individual, utilitarian, nonutilitarian, team recreational

[illegible]

concern the nature of the experience, the way in which its many manifestations are interrelated, its function in the total life of a people, then such categories are too simple These are dynamic problems that go beyond mere classification, and here as in all phases of the study of culture, it is in dynamics, not descriptions, that the key to understanding is to be sought

If we wish to understand the role of sports in the Fascist and Nazi cultures of pre World War II it is not particularly important to know which sports were so vigorously promoted but why, how, and for what purpose

Cultural research has shown that there are certain 'common denominators in all cultures, and has accented the ways in which people are alike rather than those ways in which people differ (39) It has also shown that it is in the leisure and play aspects of human culture that the hard crust of conservatism that divides one people from another is at its weakest (27) It has demonstrated that the ways of satisfying the needs of a people grow out of the culture of that people, and any culture functions best when it comes nearest to achieving a balance between the needs of a people and the resources and institutions existing to meet these needs Such research has [illegible] adolescents' struggle for

[illegible]

all powerful 'success" drive in American culture with some of its resultant implications (35,21)

THE COMPLEXITY OF THE ROLE OF SPORTS IN CULTURE

Research has shown that sports always play a complex role in cultures from the simplest to the most highly developed Underlying their obvious identification as amusements and pleasurable tests of physical supremacy are often unstated but implicit functions in the culture As old as the history of sport itself is the story of the use of sport as an instrumentality for accomplishing something else

Using as an example one of the most ancient of all sports, wrestling, it can be shown in its various historical roles as (1) a legal and judicial mechanism for settling the boundaries of rice fields in the Philippines and villages in Pukapuka (2) a part of initiation and puberty rites, (3) a means of selecting a mate, (4) a demonstration of the prestige and power of a tribal chief and (5) as a means of insuring a successful harvest

Trial by wrestling was used throughout Ifugao, preeminently to settle cases of disputed rice-field boundaries Since a rice terrace maintained by a stone wall was a decided rarity in the Ifugao country of the Philippines, boundaries were subjected to the inevitable processes of nature Erosion by rainfall in wet weather caking and crumbling in dry weather, meant a boundary not well marked and disputes were sure to follow These were settled by wrestling matches The reasoning behind this practice was that the ancestral spirits of the contestants knew which party was in the right, just where the true boundary was and would see to it that he who was right would win In spite of this expressed faith in supernatural intervention the Ifugao were sufficiently practical to insist that the wrestlers be approximately evenly matched Owners of adjacent fields could do the actual wrestling or might choose champions to represent them Disputes between kinsmen resulted in matches usually friendly, but between those not related there was often a great deal of very unfriendly feeling.

On the day selected for the match the two parties met at the disputed boundary, and took up a position at opposite ends of the disputed land Midway between the contestants stood a party of the kinsmen of each man along with the family priest After lengthy prayers by the priest, each of the adversaries was led by one of his own kinsmen to the spot where the first wrestling was to occur This was very ceremoniously done, and suggested the heralding of the champions as in feudal days

The contestants often worked themselves down half thigh deep in the mud, water, and slime of the rice field Finally, amid the shouts and loudly chanted prayers of the spectators the wrestling began Each man attempted to push his opponent into the territory that the opponent was defending and to down him there If A threw B into B s field say 10 feet from the line on which they were wrestling A won 10 feet of the rice field at that point. Eventually there was a fall that capsized one or both of them in the black

mud, and one point in the boundary was thus determined At intervals of 15 to 20 feet along the disputed boundary a rematch was held The new boundary was then established at a line running through every point at which there had been a fall (3)

On Pukapuka, an atoll in the Northern Cook Island Group, anthropologists learned how the boundaries of the villages had been settled more than 300 years before their arrival A form of stick wrestling called *tutuki* was the means employed In this technique a stick of *wetau* wood, four to six feet long was grasped by two men facing each other, with each trying to push his opponent backward The position of the weapon dictated the advance or retreat of the boundary Pairs of opponents stationed along a provisional boundary began the struggle at a given signal It was permissible to insult, grimace at, or threaten one's opponent, but each contestant was honor bound to stop wrestling when his opponent relaxed, thus giving him time to recover his breath Also permitted were attempts to edge the opponent's hands off the end of the stick, to twist the weapon from his hands, or to throw him off balance by wrenching or twisting the stick or by grasping him around the waist The wrestling continued for seven days and when finally

[illegible]

a formal report was made at the village meeting The decision usually in

[illegible] as usually [illegible]

months' period

For the boys this meant a trip to the reserves to gather nuts on each of two days After the boys had filled the big canoes with nuts, and been allowed to [illegible] they sailed in the

[illegible]

canoes beached, the challenger leaped to the shore and engaged his opponent before the assembled people Often there were several bouts between the graduates and the young men's group If a graduate champion defeated the champion of the young men's group he gained great renown and the right to call himself champion of the island This wrestling event on the evening of the second day ended the rite of adulthood and the boys were

custom for girls to

rch of a husband at

tended the public exhibitions of athletic skill armed with a small bag of flour The choice was signified by the girls sprinkling the flour on the head of her chosen one, whereupon the athlete's father immediately entered into negotiations with the parents of the girl (48)

Ancient Hawaiian chiefs customarily kept a stable of good wrestlers in their retinue When a chief was expected, in whose train were any distin guished wrestlers, it was customary to send a challenge previous to his arrival to permit his host to prepare as best he could for the contests to fol low Ellis, writing more than 150 years ago, evokes a vivid picture

It is not easy to imagine the scenes that must often have been presented at one of their *taupitis* or great wrestling matches, when not less than four or five thou sand persons dressed in their best apparel and exhibiting every variety of costume and brilliancy of colour were under the influence of excitement One party were drumming dancing and singing in the pride of victory, and the menace of defiance while, to increase the din and confusion, the other party were equally vociferous in reciting the achievements of the vanquished or predicting the shortness of his rival s triumph (18)

Stories of the ancient Japanese Empire are dotted with incidents related to wrestling In the eighth century it is reported that the Emperer instituted wrestling as a part of the ceremonies of the autumn festival of the Five Grains Since the year proved a fruitful one, the custom was continued To

Fair throws consisted of 12 lifts, 12 twists, 12 throws, and 12 throws over the back The wrestling ring was constructed of 16 rice bales in the shape of 1 large bale, supported by 4 pillars at the 4 points of the compass (15)

SPECTATOR BEHAVIOR

A recent study of Kistler (29) is concerned with an attempt to explore

since that time It also suggests that an understanding of the behavior of spectators might more profitably be sought in the realm of custom, conven tion, and cultural pattern than in the realm of ethics and morality Two ex amples from cultures of widely differing levels of development will serve to illustrate Bryson (11) reports that in the conduct of dueling contests in 16th century Italy the spectators were such a problem that among the cir cumstances under which a duel might be postponed was included 'if there was interference by disorderly spectators ' It was customary before the combat for a herald to make a proclamation to the spectators warning them that the penalty for such offenses as being present with weapons, or entering

the dueling field were punishable by confiscation of property and corporal punishment (such as the amputation of a hand!) Spectators were also warned to refrain from speaking loudly, coughing or spitting, or doing any thing which would attract the attention of the duelists

Among many Polynesians the prelude to a wrestling match was the concerted chanting by spectator partisans of one party of the most derisive and insulting remarks they could fashion to the spectator partisans of the opponent Once the match was finished bedlam ensued "The vanquished was scarcely stretched on the sand, when a shout of exultation burst from the victor's friends Their drums struck up, the women rose, and danced in triumph over the fallen wrestler, and sung in defiance to the opposite party" (18)

THE RITUAL FUNCTION OF SPORTS

The most cursory acquaintance with sports in the cultures of man will reveal their importance as ritual Yet one must be wary of the blanket assignment of a strictly religious motif to all games and contests of all eras but our own This is a circumstance in which perspective is improved by the intervening lapse of time While frequently held in conjunction with a religious ceremony and inseparably intertwined with religious ritual, it might

United States

There seems to be a widespread failure (or refusal) to appreciate how much the element of ritual enters into our own publicly staged sports contests The skeptics (and those not imbued with the cultural point of view) immediately decry this with the "facts"—that such contests are business enterprises, staged for profit, and far removed from any comparison with ancient or archaic times Yet college sports have taken on a meaning far beyond the actual "game," a fact which those controlling (or attempting to control) such activities sometimes fail to realize

Culturally—ritualistically—such sports contests often form a link between

child by the childless

In these days of rising land values and growing pressures for space to expand the colleges and universities, why are the football stadiums not demolished to make room for laboratories of science and research, and for conventional classrooms? From the cultural point of view one answer might be that a stadium (so far—in our culture) is something infinitely more than

a huge construction of wood, steel, and concrete Each one has a personal history, and while each means many different things to different people, a stadium always stands as a symbol of man's love of a contest, spectacularly staged They are monuments to the pride of individuals, institutions, and nations in the skill and prowess of their youth They are an affirmation of a philosophy of life that insists man's life is better and fuller for having such moments of excitement and splendor, and that fitting homage should be paid the heroes who bring such color and emotion into the life of the average citizen

SOME HINTS TO THE INTERESTED INVESTIGATOR

One of the first things the student must do is to learn to disregard the sweeping statements made by some well intentioned writers on the history of sports and games For example Primitive man likewise was too busy to feel any need of games It was only when civilization brought periods of peace and security to certain nations that games were invented ' (10) Compare this statement with the description of William Ellis, that intrepid missionary to the Society and Sandwich Islands "Freed, in a great degree, so far as the means of subsistence were concerned, from anxiety and labour the islanders were greatly devoted to amusements war, pagan worship, and pleasure, appear to have engaged their attention, and occupied the principal portion of their time Their games were numerous and diversified, and were often affairs of national importance' (18) Or consider the New Zealand Maoris who worked hard during the periods of crop-planting and harvesting, but once the crops were gathered and stored gave themselves wholeheartedly to the Arts of Pleasure and of Joyfulness"

The picture of nonliterate man which emerges from the research of the cultural anthropologist and the ethnologist is not of the overworked beast, automaton and infantile, driven eternally in a constant search for food and shelter This is not true of the African continent, of the American Indian as he was before culture contact had so greatly modified his way of life, and it was certainly not true of the Polynesians, who had what is probably the highest standard of leisure the world has ever known (27)

A prime requisite of the student interested in cultural research is the capacity to achieve a high degree of objectivity in examining the sports of other cultures If such data are to be judged against a value scale of present-day western civilization their contribution may eventuate in nothing more than amusement or astonishment at the strangeness" that emerges and the enhancing of self satisfaction with the way things are currently done in his own culture

Conversely the studying of the role of sports in other cultures throws an interesting light on the role of sports in our own culture, and the discovery of unexpected similarities may prove a delight to the investigator For ex

ample, the Maoris contrived water wings for their children in teaching them how to swim Taking two dried out gourds and tying them together with a piece of flax, so that one could be fitted under each arm of the learner, and flaring out to their job of keeping the child buoyant, they have an extraordinary resemblance to modern inflated bits of rubber which we use for the same purpose (8)

Knowing how the peculiar and particular language of sports has infiltrated the English tongue, it is exciting to discover that this is also true of other languages Disc pitching was a favorite indoor game in Samoa A community set of discs, owned by the young men of the village, were kept in a large coconut shell cup We find a Samoan saying denoting *finality* is translated as The discs are all in the container" (12) Few modern golfers take more pride in their favorite driver than the Fijian did in his favorite *tinqua* This was a game played by throwing from the forefinger a reed of three or four feet long, armed with a six inch oval point of heavy wood While the reed shafts might be cut from the brush as needed, good players regarded their ironwood heads with great pride (49)

THE STATUS QUO, WITH PROMISE FOR IMPROVEMENT

Within the confines of professional publications in the United States the quantity of reported research in sports and physical education utilizing the cultural approach is not extensive The pages of the *Research Quarterly* of the American Association for Health, Physical Education and Recreation reveal few studies that could be classified in this area Stumpf and Cozens (47), and Dunlap (17), demonstrated in studies on the Maoris, the Fijians, and the Samoans that an understandable and fairly comprehensive picture may emerge when thorough investigation is applied to tracing the interrelationships of sports to other elements of the culture within the microscopic world of modern primitive societies An attempt at utilization of the cultural approach is also to be found in one book published in 1953 (14) and another in 1956 (26)

If this were the total story it would seem a tale hardly worth the telling, but it is not The growth of awareness of the importance of such investigation is manifest in many ways that have so far not produced much actual research, but which promise well for the future

In 1951 the American Academy of Physical Education invited Margaret Mead [illegible] which she discussed the

The list of microcard publications in health, physical education, recreation, and allied areas contains a few titles which indicate that here and there the interest in such research is germinating and sometimes bearing fruit (20,2,34)

The untimely death of Frederick W Cozens in 1954 interrupted a promising program of cultural research which had resulted in half a dozen master s theses and stimulated the interest of many students in research of this type (17,45,42,19,9 22)

The February, 1955, issue of *The Journal of Educational Sociology* contains several articles which not only utilize the cultural approach, but also illustrate the importance of the use of such an approach in interpreting the field of sports to students and scholars in another discipline (38,50)

A recent UNESCO publication, *The Place of Sport in Education* is indicative of an expanding interest This comparative study was conceived with the idea of provoking discussion and giving rise to further studies (41) Two books are particulary noteworthy in this regard One is written by the Dutch historian Huizinga, titled *Homo Ludens* (25), and is indispensable reading for any student interested in the role of sports in the cultures of man Another, of much less ambitious scope, is presented in the study of the origins of ball games, *Ball, Bat and Bishop*, by Robert Henderson (23)

Culture, representing the widest context of human behavior, is as vital an area of study for physical educators and other students of sports as it is for psychologists, historians, linguists, philosophers, theologians, and anthropologists We need an understanding of the processes and products of culture,

There is perhaps no better way to bring this discussion to a close than with a quotation from a recent volume of the College Physical Education Association *Proceedings* "As we look around us and see the deep roots and great influences which sports exert as an element of our culture, what do we know *about causes, effects and* social controls needed in the great American scene?" (16)

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MARVIN H EYLER

The Nature and Status of Historical Research Pertaining to Sports and Physical Education[1]

This chapter is comprised of two main parts (1) a review of the nature of *historical research in sports and physical education and* (2) *a discussion of the status of historical studies pertaining directly or indirectly to sports and physical education*

Part I—Nature of historical research History, as existing in men s minds can be classified into three types (1) *past facts (actuality),* (2) *remains of the past (artifacts) and* (3) *re-creation of the past (historiography) The purpose of historical research is to locate and test the remains (artifacts) left society by present and preceding generations and to utilize such criti cally tested evidence as a basis for either a synthetic re-creation of the past or an explanation of the present in the light of pertinent antecedents so that ultimately truth may emerge Two main approaches to historical re search can be utilized One approach is to create a synthesis of what has actu ally happened based upon the use of documents and artifacts The other approach is an attempt to explain the present status of sports and physical* [illegible] *tecedents In some instances a com* [illegible]

For convenience the 158 references [illegible] *d contemporary* [illegible] *ports and* [illegible] *not gen erally known Historians in general and physical educators in particular, have paid little or no attention in recent years to the historical aspects of*

[1] Sincere appreciat [illegible] of Illinois and to D [illegible] their invaluable aid in [illegible] Dr Seward C Staley Dean College of [illegible] University of [illegible] Dr Deobold Van Dalen Professor of Physical Education University of [illegible] for their timely suggestions

sports and the effects sports have upon a culture Some evidence exists to indicate that there is a general lack of historical background on the part of the graduate student pursuing advanced degrees in physical education Under the topic, needed research, nine general areas are suggested for the student interested in historical research

NATURE OF HISTORICAL INQUIRY

History is concerned with a study of man in a time sequence History, therefore, possesses a subject matter which involves both single or individual facts (5,146) and a plurality" of facts (12,6) Some writers believe that historical investigation of man and his acts involve only a statement of mere past activities or events (9,159) However, authentic historical research will embody 'unique' events (4,19), "unusual" happenings (13,19), and/or significant facts (1,85) To the writer, the "unique' approach seems to be the most valid

If history is viewed as a science, it can only be a reasoning science It is quite impossible to control conditions or introduce extraneous or artificial stimuli in a historical study of man Therein lies the distinctive difference between a reasoning science and an experimental science It is at this point that the reasoning science acquires a difficulty not experienced in experimental sciences, that is, in the reasoning sciences as it pertains to the study of man in a unique order of events, the events are past actuality and can never be reconstructed exactly as they happened nor can they be altered or changed—simply because of the nature of past actuality

PURPOSE OF HISTORICAL RESEARCH

The purpose of historical research is to locate and test the remains (artifacts) left society by present and preceding generations and to utilize such critically tested evidence as a basis for either a synthetic re creation of the past or an explanation of the present in the light of pertinent antecedents

HISTORIOGRAPHY

History, as existing in men's minds, can be categorized into three types (1) past facts (actuality), (2) remains of the past (artifacts) and (3) re-creation of the past (historiography) In the main, historiography is a method of re-creating past actuality with the indispensable aid of the remains of the past At best, the histor [illegible] from past actuality and is quite depe [illegible] upon genuine artifacts He, therefore, [illegible] mutation and of changing ideas Further, he must possess a high degree of critical insight so that he can discriminate between the genuine and the

spurious Even after the evidence has been shown to be genuine, historically speaking, he must be wary of each subject studied (artifact, document, etc) as some of these materials are more trustworthy than others, depending upon the character and competence of the recorder as well as the circumstances involved

HISTORICAL CRITICISM

No attempt will be made to present a detailed discussion regarding logical order in historical method except to mention the use of external and internal criticism as tools in verifying (external) and authenticating (internal) the evidence The term evidence, as used in this paper, consists of many kinds of historical material It includes more than written documents Artifacts form an important part of such evidence More specifically, such evidence might well include a Roman stadium, a vase painting, a coin an early golf ball, etc It should be noted that external criticism is not concerned with the reliability of the source or the veracity of the statements made by the author External criticism is more closely concerned with answering the following types of questions regarding documents, statutes, vases, etc what kind of a document or artifact does it purport to be? If a document, who wrote it? What was the purpose of the artifact or document? Under what circum stances was the document written or artifact uncovered?

In contrast, when attempting to authenticate evidence, internal criticism attempts to answer such questions as What did the author of the document really say, or what is the real nature of the artifact? If a document, what do the words the author used really say? Did the words convey what was

who was not an eye witness, how many times removed from the event was the witness? Evidence to be credible should be attested to by at least two independent witnesses of the same event, who recorded immediately, and who were not actually mistaken or deceived Such accounts should not differ in important points nor should they agree in every detail (14,249)

APPROACH

as narrative history, is an attempt to re create past actuality This technique has been most frequently attempted by the student of history Further, it is the approach utilized for the most part in the sources cited within this chapter

The second approach, equally if not more vital and yet attempted only infrequently, is based upon cause and effect Causes are not generally subject to direct observation Instead they must be reasoned from available evidence (6,223) In this method the social, economic, political, religious, and educational conditions of a country or locale are studied in an attempt to ascertain "the before and the after' (13,70) What were the causes and effects of certain pertinent antecedents upon contemporary problems in the field of *sports and physical education? Why, for example, was there such a tremendous* increase both in the number of sports and in the amount of participation in these sports during the last three decades of the 19th century in the United States? Part of the answer will most likely be found in a study of the causes and effects of the political, the social, and more specifically in this case, the industrial conditions of the country

Whether the historian attempts to interpret a given present by its antecedents or create a re synthesis of past actuality or use a combination of both approaches, his ability to successfully accomplish his purpose is dependent upon the availability of credible documents and/or artifacts, upon such evidence being critically weighed, and upon orderly discipline, which is indispensable in the quest for historical validity The correct utilization of these approaches will certainly aid in the development of a more thorough understanding of current athletic and physical education problems

SOURCES

of the past, in truth or transmitted for the purpose of informing posterity The first would be admissible as primary evidence and the latter as secondary According to certain historiographers, some examples of primary sources are archaeological remains such as vases, stadia, Greek and Roman statues, etc, personal records, confidential reports, public reports such as press dispatches, government publications, Census Bureau Reports, and under certain conditions, even such material as fiction, song and poetry, folklore, etc, can also be classified as primary

Secondary sources, or sources at least once removed from primary evidence, often are classified as tradition and, in some instances, might be treated as remains However, the important thing to remember here is that traditions contain the records of impressions made upon man s mind, not necessarily the facts (4,44) Under certain circumstances such records of impressions occur in some of the primary sources cited above

The selected sources cited in this chapter have arbitrarily been divided into three main divisions (1) ancient sources prior to A D 1000, (2) early sources from A D 1000 to A D 1800, and (3) contemporary sources from 1800 to date The numerous sources included may give the impression that the historical method has been used quite extensively in the field of sports and physical education This is partly true if one considers the great amount of sporting literature of a historical nature written and published before 1900 pertaining to specific sports However, this impression is quite erroneous if one attempts to analyze the nature of these studies Such an analysis reveals, among other things, that a considerable portion should be classified as narrative history usually arranged along chronological lines Only a modicum of effort has been expended to indicate meaningful cause and effect relationships between the nature of sports and other social phenomena In addition,

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and of themselves histories of sports and physical education These sources are included, however, because they contain rich storehouses of information relevant to the beginnings and the development of sports and physical education Further, although biographies and autobiographies constitute an im

(some of which have been prepared in a most credible manner, such as F P Magoun s *History of Football from the Beginning to 1871*), as such a list would unduly lengthen this chapter beyond all reasonable bounds

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STATUS

The historical literature pertaining to sports and physical education is extremely diversified and in many instances not generally known, at least in the sense of being readily available By diversity of sources is meant the immense range of written material which houses information of a sporting and physical education nature as well as many and varied artifacts In an historical approach to tennis, for example, sources range all the way from a defini

the study such as Julian Marshall's *The Annals of Tennis* to a series of early English and French parliamentary enactments

The comparatively rapid growth and development of sports and physical education in the United States since the last 3 decades of the 19th century indicate a real and pressing need for studies which would give insight into the present status of sports and help analyze the actions and interactions which have helped to create the current conflicting ideologies regarding the place and nature of sports and physical education in American culture His torians in general and physical educators in particular have paid little or no attention in recent years to the historical aspects of sports and the effects sports have upon any culture The latter a sociological view most likely will not be completed without historical studies covering a wide range of subject matter pertaining to sports and physical education to act as foundation

As has been reported by Leighton Johnson (8 157) and Dorothy Ains worth et al (2 125) the use of historical method as a research tool and the reporting of the same has decreased in number in an alarming rate during the past three decades Thomas K Cureton (3 24) reported only 20 doctoral theses involving the historical bibliographical approach from 1930–1946 which was slightly over 4 percent of cases in a sample of 420 studies Un

Sciences where this kind of thinking and thus research is engendered Be that as it may the profession is in danger of losing one of the most im portant means by which it can further obtain and maintain perspective in educational problems when historical studies pertaining to sports and physi cal education are not fostered or stimulated at the graduate level in institu tions of higher learning

NEEDED RESEARCH

1 Approximately one fourth of some 230 known distinct, and currently practiced sports and athletic activities have been treated historically Fur ther the origins and developments of many recently evolved sports and

athletic events, such as code ball, model motor boat racing, paddle ball, petecca rio, touch football, and others, have not been determined Comparable historical and cultural studies, as well as psychological studies, might shed light on the question why certain sports are popular and others are not popular in this society

2 Studies are needed which would point out the causes and effects of certain pertinent antecedents upon contemporary problems in the field of sports and physical education

3 A need exists for a series of studies treating the history of many extinct sports These studies would help fill the gaps so noticeable in an examina

on the sporting practices of Colonial America, of the national period in America, and of contemporary America

5 Studies regarding the histories of games distinctive to certain cultures are all too few in number Except for a few works from the anthropologist and the ethnologist, this type of research is practically nonexistent One sees the proof of this when one considers the very few studies of this nature attempted by the physical educator Two notable exceptions to this statement are the studies of Florence Stumpf and Frederick Cozens (11,198) and of William Goellner (7,147)

States For example, one such study might be a history of professional athletics in American colleges and universities and the subsequent broadening of the American concept of amateurism

9 Studies should be attempted to ascertain why the United States has become such a sports minded nation, the effect of such sports-mindedness upon the American mind and thus its place in American culture

CONCLUSIONS

Many of the historical studies pertaining to the field of sports and physical education appear to have been approached from a very broad historical research viewpoint, certainly not along the lines that have been developed in this paper The tools to ascertain historical validity have not been used with

tion One example of this questionable practice can be found in the athletic game of tennis Joseph Strutt, who for the most part was a careful antiquarian, stated in his *Sports and Pastimes of the People of England*, that the earliest mention of the term tennis was found in 1388 in a restrictive act prohibiting certain sports in favor of archery Since 1801, numerous writers of sports history have used this proclamation of Edward III and the date, 1388, as indicating the earliest reference to the game of tennis in the English language However, a careful and quite exhaustive search into the then contemporary chronicles, statutes, restrictive acts and parliamentary enactments failed to reveal any mention of the term tennis (or any term which might be construed to mean tennis) This particular statute did prohibit the playing of football, club-ball and handball in order to encourage the practice of archery It was not until almost 100 years later (1463–64) during the reign of Edward IV that an English edict mentioned the term tennis and that was in a proclamation against the importation of tennis balls (spelled Tennys Balles)

Noticeable exceptions to the questionable use of historical inquiry exist Some of these exceptions are Kenneth Freeman s *Schools of Hellas* E Norman Gardiner's *Athletics of the Ancient World* and *Greek Athletic Sports and Festivals*, Elizabeth Rearick s *Dances of the Hungarians*, Julian Marshall s *Annals of Tennis*, Theodore Stern s *The Rubber Ball Games of the Americas*, Joseph Strutt's *The Sports and Pastimes of the People of England* and Fred Leonard George Affleck s *A Guide to the History of Physical Education* It is also encouraging to note that a history and philosophy section has recently been added to the structure of the American Association for Health, Physical Education, and Recreation

The dearth of scholarly historical research in sports and physical education may in part be the result of a current concept, held by some experimental research personnel, which has the tendency to limit all attempts of a historical nature to a position where, if it is to pass an arbitrarily imposed research criterion such as timeliness and pertinence to the field, it must answer or throw light on a contemporary problem in every instance In other words, inquiry must always have a specific purpose In such a philosophy, there appears to be little or no justification for a historical research problem that poses the ascertainment of truth in and of itself This is a severely restricted viewpoint In reality, this limited concept is based upon only one specific segment of the comparative function of history Nor does it include other equally important functions such as (1) a means of measuring progress or retrogression, (2) a means to study the record of experimentation of man including achievements as well as failures, and (3) a means of demonstrating the close relationship existing between certain elements in a culture and the status of physical education in that culture A study indicating the function last stated could attempt to answer why one's religious

beliefs can promote the development of the physique and physical prowess, as in the early Greek civilization, while another religious belief stifles such development, as in the movement called asceticism

Finally, it would seem most appropriate to propose that a greater emphasis be placed upon studies of a historical nature on the graduate level in American colleges and universities, and, further, that such encouragement should not employ only the ascertainment of facts as a means of describing past actuality, but also include a concerted effort to develop appreciations and an ability to interpret and compare facts, as well as to acquire and maintain perspective In short, students who are seriously interested in attempting historical studies in sports and physical education should not only have a good foundation in history, but should become well disciplined in historiography, a tool that is vital to historical validity

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PART VI

Therapeutic Aspects of Exercise and Sports

34

JANET A WESSEL AND
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Therapeutic Aspects of Exercise in Medicine[1]

SUMMARY

This chapter is intended to provide a brief analysis of some present day uses of exercise in medicine and to take into account the scientific work being done to determine quantitatively the outcomes achieved through clinical exercise techniques The fundamental questions as to the effects of exercise apply in relation to therapeutic exercise as they do to exercise and sports generally

Therapeutic exercise is defined as prescribed bodily movements used to restore or ameliorate specific functions in persons suffering from various physical and/or mental disorders

Persons interested in the role of exercise in the maintenance and improvement of health have raised important questions concerning the meaning of the word "exercise," the forms it may take, the relationships that exist among various forms of exercise, and the manner in which types of exercise should [illegible]

[illegible] *exercise program active and/or passive may be administered autonomously, mechanically, or manually One of the chief therapeutic values of passive exercise is the promotion and a maintenance of "normal joint motion" Active exercise, static or kinetic, is one of the most important and effective modali-*

[illegible] the Correlation of Physiology and Therapeutic Exercise which were sponsored by the Office of Vocational Rehabilitation United States Department of Health Education, and Welfare, and the American Physical Therapy Association

ties in the clinical application of exercise Some of the major therapeutic uses of active exercise are improvement of strength, endurance, and neuromuscular reeducation

The prescription for exercise is based upon the knowledge of the patient's condition as a whole and is used in conjunction with whatever medical and surgical measures are necessary Each type of exercise has a unique physiological effect which gives to it a different therapeutic objective Then too, the method used in administering the exercise affects the physiological responses and derived therapeutic objectives The therapeutic objectives for which exercise is prescribed in the clinical fields of orthopedics, neurological, and general medical and surgical conditions generally include maintaining and/or augmenting strength, power, tone, range of motion, and coordination, and maintaining and/or improving general body and muscular endurance

The validity of some of the currently popular technics of applying strength

clinical strength tests Clinical procedures employed to restore or maintain 'normal joint range' should be evaluated, and the validity and reliability of the different instruments used to measure range of joint motion should be studied

Research and a great deal of clinical observation make it clear that prolonged bed rest and absence from normal activity is not the sina qua non of the treatment of patients suffering from medical and surgical conditions On the other hand, quantitative studies to investigate and evaluate endurance programs used to assist the patient in the development of sustained function without harm or injury are essential for future progress Selye's work on stress and the formulation of the "adaptation syndrome" may have important clinical applications in relation to fatigue brought about by therapeutic exercise

In the past the techniques used for administering exercises clinically have

exercises—suggest the future role of exercise in total patient care When we
have acquired suffic
exercise is capable of
brought about, and
the results obtained,
science as well as an art It is clear that the development of a general concept of all exercise will come through the basic research from many disciplines, directly or indirectly With this development we will be able to distinguish between and among the various forms of exercise and make the sci

entific applications of exercise for general well being as well as a therapeutic modality in total patient care

INTRODUCTION

An interesting problem of semantics faces all professional persons concerned with the role of exercise in the maintenance and improvement of health What is meant by the word exercise? What is its structure? What forms may it take, e g , sports, dance, athletics, swimming prescribed movements, daily living activities? What relations exist between and among the various forms of exercise? If we pursue this question further, we find it grows into a complex of closely related questions—what? why? when? where? how? and who? Our answers to these questions may be quite heterog

cise—movement Beyond this point definition is difficult as one immediately becomes involved with specifics (1) What are the distinguishing characteristics of movements used therapeutically, recreationally, or as preventive medicine? (2) What are the specific characteristics necessary for

in total patient care

In ancient times as today the rationale for the use of exercise appears to have been based upon the physiological principle of use and disuse" This concept of exercise would seem to connote that 'function begets function"

In reviewing the past, the techniques used for administering exercises clinically have been primarily an art rather than a science The results obtained from the different methods of application of exercise for the treatment of specific disorders were rarely quantitatively evaluated Most often changes in methods or procedures were brought about through clinical ex

of exercise in medicine and the extensive research in this field promise more scientific evaluation of techniques to determine quantitatively the outcomes achieved through various exercise techniques Even though there is con siderable diversity of exercise 'systems' in the clinical application of exercise, there does exist today some agreement regarding the basic principle of exer cise usage in medicine

Two developments—(1) a more scientific approach to the application and evaluation of exercise techniques and (2) an increase of basic research con cerned with determining the values of exercise—suggest the future role of exercise in total patient care The time is coming when the various forms of exercise will be prescribed to achieve a clinical objective during different phases of patient care just as drugs are prescribed and regulated as to dosage

uation of the results obtained, exercise will acquire full status in medicine as a clinical science

In the present chapter, the discussion will be confined to the therapeutic use of one form of exercise—specific exercise movements used to promote tone, strength range of motion, endurance, and neuromuscular control However, obviously many of the principles and techniques of therapeutic exercises presented in this chapter have direct application in the programs of other forms of exercise, e g, swimming, dance, sports, daily living activi

idea should be presented There is a need to unify and clearly define the fields in which exercise—all forms of human movement—is an important therapeutic modality in total patient care as well as potential use as preven tive medicine At present we seem to be dealing with principles that have been proven to be the same for all forms of exercise Actually, what we need is to study each form of exercise in its own terms Such a study should be more rewarding than the usual passionate declaration that all exercises are alike, only the materials differ and the personnel who administer them Such a study should guide us to exact relations existing between and among

CLASSIFICATION OF THERAPEUTIC EXERCISE

Therapeutic exercise is defined as prescribed bodily movement used to re store or ameliorate specific functions in persons suffering from various physi cal and/or mental disorders The therapeutic objectives of exercise generally

include maintaining and/or augmenting strength, power, tone, range of motion, and coordination, maintaining and/or improving general body and muscular endurance, promoting relaxation and thus encouraging emotional, social, and mental adjustment or readjustment, developing or redeveloping of daily living activities and occupational skills and helping to prepare the patient mentally, emotionally, and physically for future treatment

There are two types of exercise passive and active (18 20 50) Passive exercise or movement is carried out by the application of external force with minimal (imperceptible) participation of muscular contractions by the patient Passive exercise, nonforced, is movement made by the application of an external force without pain or muscle spasm and within the limits of free range of motion (44) Passive exercise forced, is movement made by the movement beyond the limits ive exercise may be done with

le by the graded participation of the patient's muscular contractions and with or without the application of external force The patient s muscular contractions range from minimal through maximal The gradation in muscular tensile force or muscular contraction developed by the patient is achieved through the graded supplemental application of external force applied manually or mechanically The amount and type of external force employed is based upon the patient s condition and the desired physiological response which most meets the clinical need

The physical therapist is concerned with the specific or focal as well as the

and anatomy Recently, an investigation of terminology relating to names used to designate various therapeutic exercises and therapeutic exercise procedures used by physical therapists was reported by Lawrence (51) Two

therapeutic exercise and procedures It would seem apparent that such analysis would entail a teamwork approach from persons in allied medical and professional fields who would give constructive thought to this problem The confusing vocabulary may in part be attributed to the diversified approach to the study of human motion (kinesiology) The use of standard terms in texts and in the teaching of kinesiology could result in the correction of much of the confusion

Many workers have proposed different systems of classification of exer

TABLE 34 1 Classification of Therapeutic Exercise Used in Physical Therapy Based upon the Functions of Muscular Contractions (Tensile Force)

Type of Exercise	Type of Contraction	Function of Contraction (Tensile Force) in Movement	External Force Opposing Contraction (Tensile Force)	Work of Muscular Contractions (Tensile Force)	Rate of Energy Supply	Some Important Clinical Uses Promotion of
Passive* movements 1 Nonforced 2 Forced	Relaxation	Permit acceleration Deceleration by external force	None*	None Slight	None Slight	Range of Motion Respiration Relaxation Facilitation Circulation
Active movements* (dynamic)						
1 Static	Constant length (isometric)	Stabilization or equalize forces to control direction or maintain positions	Equal	None	Increase	Muscle, tone, size Muscle strength Facilitation Circulation Relaxation
2 Kinetic	Shortening (isotonic)	Acceleration (+)	Less	Positive	Increase	Muscle strength Muscle tone Muscle size Endurance (muscle) and total body Facilitation Coordination Postural sense Relaxation
	Lengthening	Declaration (−)				

* Movement is the result of external force
* Movement is the result of [illegible]

cise (18 20 24 50) Some are extensive and cover all aspects of exercise used in medicine (93) Some are limited to a more functional classification pertaining to specific therapy The classifications listed below have been proposed, not to add another approach to this subject, but as an attempt to correlate exercise terminology with terminology from physiology, physics, and anatomy It is hoped that this approach will stimulate creative thought to this problem of vocabulary or language of exercise It is believed that the classification covers all clinically important aspects of therapeutic exercises used in physical restoration and/or amelioration

It may seem that an exercise classification presents the different types and purposes of exercise in a static and unrelated manner However, this does not exist in the clinical application of exercises for two or more types of exercise may be prescribed in one treatment program as well as many different combinations or sequences The exercise program active and/or passive may be administered autonomously, mechanically, or manually Many exercise programs are administered in conjunction with other modalities used in physical therapy such as heat, water traction, and electrotherapy (29 4) What is essential is the prescription for exercise that most nearly answers the clinical need, and this should be determined by the physician Basically to prescribe exercise for a specific clinical need requires not only considerable knowledge of the patient and as much about his condition as possible, but also considerable knowledge of the patient and as much about his condition as possible, but also considerable knowledge of the different types of exercise and their characteristic physiological responses

SOME PHYSIOLOGICAL ASPECTS OF EXERCISES HAVING IMPORTANT CLINICAL SIGNIFICANCE

There is no rigid rule employed in prescribing the type of exercise for a specific clinical entity Just as a physician delimits his prescription to a specific drug and regulates its dosage to achieve specific effects so also must exercise be prescribed and carried out to achieve specific therapeutic objectives desired in the treatment of abnormal conditions With the knowledge of different types of exercise and their characteristic physiological responses, the proper exercise or combination may be selected that most nearly fulfills the clinical need and therapeutic objectives

Passive Exercise

One of the chief therapeutic values of passive exercise or bodily movement is the promotion and maintenance of normal joint motion (44) Passive exercise or movement, nonforced, made within the limits of free range of motion which does not cause pain or spasm has been found to assist in the prevention of contractures, adhesions, capsular tightness, and muscle shortening (29,41,44 79) Passive exercises are important and ef

fective in maintaining normal joint range while awaiting the restoration of active motion in many neurological conditions including cerebral vascular accidents, poliomyelitis, and peripheral nerve injuries (41,79,83) Passive exercise has been especially effective in helping to prevent the development of fibrotic or myostatic contractures during re innervation in peripheral nerve injuries (29 41,79) Reports of the value of passive exercise in reducing the amount of reconstruction surgery in patients with permanently paralyzed muscles due to poliomyelitis are numerous (44,83)

Passive exercise has been employed to induce relaxation and sleep (39,83) Persons who exhibit what is called "residual neuromuscular hypertension" have been taught to reduce this tension through rhythmical and continuous passive movements Another important therapeutic value of passive exercise has been found to result from the fact that movement of a limb increases respiratory rate through the stimulation of the various peripheral receptors in the skin, ligaments, and joint capsule (23,29) It is also possible that therapeutic value is derived from the stimulation of proprioceptors by the stretching and shortening of muscle during passive exercise However, it has been shown that the degree of proprioceptive influence is directly related to increased resistance of the muscle contraction during active movements (kinetic, 32,42) Still, there may be some value in the early stages of neuromuscular reeducation in the employment of passive exercise Passive exercise has therapeutic value in assisting venous and lymphatic return (16)

Passive exercise, forced, are movements carried beyond the existing free range of motion and may be done with or without the use of local or general anesthesia Passive forced movements are used to stretch intra articular and extra articular structures which limit the joint motion in an attempt to restore normal joint motion and minimize pain if present (6,95) Structures limiting normal joint motion include the formation of adhesions, adaptive shortening of fascia, tendons, muscles, ligaments, and joint capsule, and the formation of scar tissue Selection of cases suitable for manipulation might include the following conditions persistent pain in or around a joint following minor trauma, osteoarthritic joints, adhesions and contractures, deformities of joints due to rheumatoid arthritis, and adhesions in tendon sheaths Forced passive movements have clinical application for peripheral nerve injuries, poliomyelitis, acquired or adaptive shortening of muscle structures, and many others (6,44,61) Mechanical application of forced passive exercise includes such means as turnbuckle plaster cast, balanced traction and splintage, and braces (41,79)

Active Exercise

Active exercise, static or kinetic, is one of the most important and effective modalities in the clinical application of exercise Some of the more important therapeutic uses of active exercise include improving strength, size, speed, and endurance of muscles, improving body endurance or stamina,

neuromuscular reeducation or the reestablishing of cortical control of simple and complex motor acts, inducing of relaxation, sleep, and general well being; developing of postural sense, improving respiration and improving joint mobility

Static Exercise This type of dynamic exercise is performed when the muscles contract isometrically without producing joint motion Exercises of this kind may be performed with or without resistance The clinical value of this type of exercise has been to maintain muscle tone and circulation when joints have been immobilized by casts, splints, pain, or some condition where joint motion (active or passive movements) has been contraindicated (16,24 41,79) In the early stages of neuromuscular reeducation, the patient has been taught to 'feel" or become "aware" of muscular contractions essen tial to the performance of a specific movement through static exercises Another clinical use of this type of exercise has been to teach relaxation by making the patient consciously aware of the feeling of being hypertense and hypotense (36,72) A more recent use of static exercise has been in the de velopment of muscle strength and muscle size by making the muscle con tract isometrically against a fixed resistance in various positions for a period of time (32,33) Also, through the work of many different investiga tors it has been found that so called 'nonfunctional parts of the body, for example an injured leg, benefit from this type of muscular contraction when the functional parts of the body are exposed to kinetic exercise involving heavy resistance It is thought that such benefits may be explained on the basis of the concept that muscles work in primitive patterns and through associated reflexes (21,32,86)

Kinetic Exercise This type of dynamic exercise is performed when the muscles contract, isotonically and eccentrically, producing single or multiple joint movement Exercises of this kind may be performed with or without (1) the weight of 2) the addition of the use of springs, cables, and opposing muscle groups on a specific body part or total body, and (4) the speed of the specific body part or total body weight The type of resistance and amount employed are commensurate with the therapeutic objective during the stages of recovery Kinetic exercises of minimal resist ance are produced clinically by counterbalancing, manually autonomously, or mechanically (18) This type of exercise has been employed principally to strengthen, to increase muscle size, and to improve endurance in weak ened muscles, to promote restoration or maintenance of joint motion, to promote endurance during convalescense, and to teach the patient move ment patterns in the re establishment of volitional control lost through dis ease or trauma (20,24 29,50,84)

Kinetic exercise employed to develop strength has become known almost universally as "Progressive Resistance Exercise" This type of kinetic exercise

is of high resistance (weight) and low repetitions (18) The term 'high" is misleading, for this type of exercise is applicable to muscles of all grades of strength Perhaps a term such as maximal may be used when such a term implies maximal related to the specific degree of strength or functional condition of the muscles involved Generally, it is thought that through this type of exercise program maximum functional strength is developed (18,32). The clinical applications of this type of exercise are extensive Some of the conditions that employ this type of therapeutic exercise are orthopedic conditions (trauma to joints and muscles, postural deviations, low back pain), surgical orthopedic conditions, neurological conditions (poliomyelitis, progressive muscular dystrophy, multiple sclerosis, polyneuritis, hemiplegia, cerebral palsy), and medical and surgical conditions, such as osteoarthritis, defects in abdominal walls, amputation, childbearing, dysmenorrhea, thoracic and abdominal surgery (12,18,20,24,26,29,69,79)

Kinetic exercises of high number of repetitions with slight to moderate resistance usually consisting of the weight of the part or body weight or water resistance are known as endurance exercises (24) The improvement of *endurance*, general body endurance or local muscular endurance, in convalescent patients is based on the general biological principle that organ function improves to a certain extent by repeated use and extension of stress while disuse leads to varying degrees of deterioration in function of the specific organ or organs in question Depending on the individual's tolerance for exercise, the patient with a program of graded endurance exercises (repetitions resistance, speed) can improve considerably the regulatory mechanics in temperature, respiration, local and systemic circulation, and assist in the maintenance of general metabolism (9,12,16,23,43) High repetitive forms of exercise may be brought about by the use of bicycling, typing, swimming dancing, games, and so forth

Kinetic exercises employed for inducing relaxation and developing postural sense are body movements with the resistance generally being the weight of the part of the body involved or the total body The degree to which muscular tension can be reduced is quite variable However, the term relaxation is used generally to indicate that a reduction in muscle tension has taken place Kinetic exercise in the form of rhythmic movements are commonly employed to promote relaxation These movements are brought about by muscular contractions moving different parts of the body alternately This kind of routine is carried out in each area of the body in a definite sequence The movements may be large or small (72) In the development of postural sense, the patient develops an understanding and feeling of balanced alignment as well as muscular contractions essential to bring about and control this position or positions through kinetic exercises (46,94)

Today one of the most valuable uses of kinetic exercises is in the area of neuromuscular reeducation In the process of reestablishing volitional con

trol, kinetic exercises are employed in many combinations and sequences Many other methods or techniques involving neurophysiological reactions along with the application of kinetic exercises are being used clinically (7,10,73)

It is in the area of neuromuscular reeducation that clinical research may be particularly fruitful The disciplines of neural physiology and physiological psychology have and are developing research in the area of motor learning much of which is directly or indirectly applicable to the problems of re

of these mechanisms altering the nature of the stimulus being applied to muscle are known, but not too well understood and, many more probably exist, of which there is little or no knowledge (25,42,59,70,81) Whatever the mechanisms involved in motor learning, it is known from clinical experiences and experimental studies that new movement patterns are learned and are not a "sequence of mosaic activations of specific muscles (70) In other words, observations indicate that learning a new motion pattern is partially

that movement (77) When one takes into consideration the complexity of this problem, it is not difficult to understand the divergent findings that exist in the field

FATIGUE AND STRESS[2]

There is considerable divergence of opinion concerning the effects of fatigue brought about by therapeutic exercise upon restoration of function (59,85) The point of issue seems to be the effects of exercise fatigue upon muscles severely damaged by poliomyelitis and other diseases The question may be raised, "Would such fatigue or exercise 'stress' produce irreparable muscle damage and/or prolong the period of restoration of function?"

(18,32,43) There is still some doubt concerning the efficiency of this type of exercise program in the early stages of convalescence How much can injured or diseased muscles take? Much work is needed to evaluate quantitatively the effects of muscle fatigue in the clinical application of specific exer

, fatigue produced
duced by exercises

[2] General discussions of fatigue and stress are presented in other chapters of this symposium

involving many muscle groups Local muscular contractions are essentially localized and produce little change in cardiovascular or respiratory function (18,23,43) However, exercises involving a large number of active muscles which demand oxygen and elimination of waste products produce considerable changes in the cardiovascular and respiratory functions Consequently, patients long inactive with reduced cardiorespiratory efficiency may be able to tolerate only local exercises (5,53) Kinetic exercises of the endurance type must be graded slowly and progressively to all for readjustment of the cardiovascular and respiratory systems (23,65,67,92)

Selye's work on stress and the formulation of the adaptation syndrome may have important clinical application in relation to fatigue brought about by therapeutic exercise (77) It seems to be established that exercise beyond the capacity of the individual could give rise to a severe stress reaction which may hinder the recovery process Considerably more research work needs to be done before the full implications of Selye's stress theory for therapeutic exercise is fully understood

PRESCRIPTION FOR EXERCISE

INTRODUCTION

The prescription for exercise has taken the place of many passive forms of treatment in total patient care since World War II (16,47,4) A word of

of exercise as well as the choice of exercise and technique of administration will vary with different clinical needs from individual to individual The future progress and fundamental values of all types of exercise in medicine to a great extent would seem to depend upon the understanding and knowledge of the exercise prescription by the physician and scientific method of administering it to meet the clinical need

Like other prescriptions, the prescription for exercise is based upon the physician's knowledge of the patient's condition as a whole and is used in conjunction with wh [illegible]
All patients should r[illegible]
exercise prescription [illegible]
status, joint and coordinate muscle responses, and status of thoracic and abdominal walls

In the administering of the exercise program the therapist should have adequate understanding and knowledge with regard to (1) the physiological effects that a specific exercise program is capable of producing in its clinical application, (2) technical knowledge of exercise procedures used

in the administering of the specific exercise program, and (3) evaluation of the patient's condition with respect to need for changes in prescription, unusual reactions of the patient to the exercise stress, and achievement of optimal results by the patient The clinical value of any exercise program is directly related not only to the exercise prescription, but also to the intelligent administering of the exercises prescribed for the particular patient

VARIABLES AFFECTING THE DESIRED OUTCOMES OF THERAPEUTIC EXERCISE

Seemingly, one of the most important causes for the ineffectiveness of an exercise program lies within the realm of poor prescription As stated previously, each type of exercise has a unique physiological effect which gives to each exercise a different therapeutic objective So also, will the manner or method used in administering the exercise affect the physiological responses and derived therapeutic objectives Thus it is extremely important that the exercise prescription include not only the type of exercise and specific exercise and its purpose, but also it must control the variables that influence the effectiveness of each exercise in the program in meeting the specific clinical need Some of the important variables or factors that must be considered include the following

1 *The precautions* what, where, why
2 *The exercise* type, purpose, how (autonomously, mechanically or manually) Conjunction with other modalities
3 *The duration* each exercise and total exercise program daily, weekly, monthly, number of exercises in the program the frequency of each exercise movement
4 *The evaluation* when, what, and how
5 *The nature of the exercise movement* slow or fast moving fixation, ballistic, pendular, oscillatory, or fixation unilateral or bilateral simultaneous or alternating
6 *The range of the exercise movement* range of each movement
7 *The rhythm* each exercise movement and total exercise program, sequence of events of work and rest for each exercise, between each exercise, and between each treatment, amount of rest
8 *The timing* the sequence of events are properly timed for each exercise movement timing with respect to when force is applied or other measures to elicit, reinforce, or coordinate muscular responses, how long force is applied, place of each exercise within the program
9 *The progression* range, load, speed, power, work, energy expended with respect to each exercise and total exercise program
10 *The intensity of the stress* load, resistance, speed, power, work, energy place of stress to the exercise movement (where placed) and how

A typical prescription form used for progressive resistance exercise is depicted in Fig 34 1

PROGRESSIVE RESISTANCE EXERCISE

Unit No ________

Name ____________________ Age ____ Date ____ Diagnosis ____________

Purpose of Exercise ____________________ Exercise Prescribed ____________

1 R M ____________________ R M ____________

No Sets of Exercise ____________________ Reps Per Set ____________

Frequency ____________________ Limitations ____________

Date																					

Date	Muscle	Power	Work Capacity	Volume	Miscellaneous

CONSIDERATION OF THE CLINICAL APPLICATION OF EXERCISE

Generally speaking, conditions for which therapeutic exercise as defined in this discussion are used fall within three major clinical fields, orthopedic, neurological, and general medical and surgical conditions There are certain other fields in addition to these but the present use of this form of exercise is somewhat limited

Orthopedic Therapeutic exercise has been used extensively in both surgical and nonsurgical orthopedic conditions (4 29,41,79) The purposes of exercise employed clinically for these conditions would include restoration of joint and muscle function, relaxation, neuromuscular reeducation, proper skills in body mechanics and postural sense, and overall physical reconditioning Some examples of nonsurgical orthopedic conditions for which exercise has been employed would include low back pain (postural and undiagnosed low back pain), deviations from normal balanced postures, residual neuromuscular hypertension, conditions of fibrositis referred to as myalgia, myositis, myofascitis, and lumbago traumatic injuries of muscle and fibrous tissue, bursitis, and periarthritis of the shoulder joint Examples of surgical orthopedic conditions utilizing the restorative value of exercise include meniscectomy, patellectomy, hip arthroplasty, fractures, and herniated invertebral disk

The therapy regimen emphasizes the following points (1) treatments of the whole man and not the disability, (2) early commencement of all therapeutic procedures, (3) progressive nature of each step of the program and [illegible] manner (17)

include poliomyelitis, peripheral nerve injuries, cerebellar ataxia, progressive muscular atrophy, tabes dorsalis, multiple sclerosis, cerebral palsy, hemi[illegible] The overall purpose of exercise em

mobility of joints, muscle spasm or spasticity, and lack of endurance

The potential expansion of exercise in the therapy regimen for neurological conditions is tremendous Basically, this expansion is being brought about by the development of newer neurophysiological concepts concerning muscle performance as well as scientific development of methods for the clinical application of known neuromuscular mechanism (75)

General Medical and Surgical Conditions As in any clinical condition, the therapeutic use of exercise is based on the knowledge of the patient's condition as a whole, and, it is used in conjunction with whatever medical and surgical measures are necessary Examples of clinical conditions for which therapeutic exercise is prescribed include cardiovascular conditions such as heart disease and rheumatic fever, respiratory conditions such as tuberculosis and asthma, and cardiorespiratory poliomyelitis, chronic fatigue, periods of bed rest and immobilization resulting from surgery, or general medical conditions such as arthritis and rheumatism, functional disturbance of the pelvic organs and postpartum conditions, digestive conditions such as visceroptosis and functional constipation, burns, and amputations (35,29,4) The overall therapeutic objectives for the clinical application of exercise would include overall physical reconditioning and body endurance, restoration of joint and muscle function neuromuscular reeducation, relaxation, and proper body mechanics

The therapeutic role of exercise, as well as all types of physical activity in the field of medicine and surgery received its greatest impetus during the Second World War Since that period many reports have been made as to the use and abuse of bed rest for medical and surgical conditions According to these reports and recent research it seems apparent that prolonged bed rest and complete absence from normal activity lead to untoward results such as hypostatic pneumonia, pulmonary congestion, acute pulmonary collapse, embolism thrombosis, edema of the lungs, loss of appetite, constipation, distention, urine retention, loss of nitrogen, potassium, phosphorous and calcium, renal stones, adaptive shortening of joint and muscle structures, atrophy of bone, loss of vasomotor tone and blood volume, bed sores, muscle and skin wasting, and phlebitis (16,19,30,48,84) With the uses of exercise for the prevention of these complications in general medical and surgical conditions has come new terminology including "early ambulation," "bed exercise," "deconditioning phenomena" and physical reconditioning programs in medicine (16,48,68)

Clinical Techniques of Applying Exercise

The evidence briefly reviewed in the previous discussion suggest that there is an ever present challenge in the selection of methods for the restoration of strength, endurance, range of motion, relaxation and neuromuscular control in the rehabilitation of the ill and disabled The widespread use of various exercise regimes in medicine today suggests that the end results of many diverse conditions can be improved appreciably by the judicious control of all exercise and activity programs It is apparent, however, that the physiological aspects of exercise must be understood in order that the exercise program prescribed is individualized to meet the particular needs of each patient, and not mere rote adherence to any one system of exercise currently popularized Also, of utmost importance for the continual effectiveness of

exercise employed clinically, is the use of a systematic approach to obtain evidence to test the efficacy of present day clinical technique for applying exercise and to support modifications of exercise technique supplied through clinical experiences

Although the effects of exercise upon physical performance are discussed in detail in other chapters, a few considerations are mentioned here because of their pertinence to needed research The general aspects of some clinical techniques of applying exercise to restore strength, range of motion, endurance, and neuromuscular control are presented here

Technique Used to Improve Strength There have been sufficient studies to indicate that exercise will within limits increase strength, and at the same time bring about concomitant effects such as muscular hypertrophy and central nervous system relearning (18,32) The investigation of the structural changes concomitant with the strengthening process showed that the number of fibers does not increase in hypertrophy but that the size of fibers increases (1). Augmentation of strength is produced through exercise eliciting the following types of muscular contractions shortening, lengthening, or isometric contractions (18,32,33,43,95) Hettinger and Muller demonstrated that (1) strength increases most rapidly when the load is approximately ⅔ of maximal strength and (2) one training session per

extension of limits of performance depends (32) Other findings reported in the same study were that gains in performance varied with the frequency of the practice session and the duration of the overload effect the speed with which changes occur were attributed to neural changes evolving concurrently, and the ability to develop maximal tension appeared to be dependent on the proprioceptive facilitation with which overloading is associated

The first serious effort made to formalize a clinical technique designed to develop muscle strength in as short a time as possible appears to have been DeLorme's heavy resistance—low repetitive exercise (17,18) DeLorme advocated repetitive exercise, 7 to 10 bouts, in which the patient tried to step up the amount of load employed Maximal resistance was increased at weekly intervals In later reports by DeLorme and others the procedure was modified to include 1 or 3 bouts of exercise with only 1 bout of maximal effort or of "overload" of 10 repetitions (18) Since the first introduction of DeLorme's "Progressive Resistance Exercise Technic" it has been modified and many variations exist in its clinical application today A recent variation ... popularly as the "Oxford Technique" (95) In this exer-

cise has recently received much attention Studies have been reported demonstrating that unilateral heavy resistance exercise which increases strengtl of the ipsilateral limb has strikingly similar concomitant effects on the contralateral unpracticed extremity (31,91) This concomitant effect appears t be neither haphazard nor brought about accidentally. It seems apparen that the effect upon the unexercised muscles may be explained in part b the teamwork of muscles in the roles of fixators in stabilizing parts of th body and in the reinforcement of associated reflex mechanism (31,57 90 91) The augmentation of strength in the unexercised limb seems to b brought about essentially by isometric contraction—nonperceptible as gros movement The use of facilitatory action and associated reflex mechanism

considered in designing exercise programs to augment strength clinically load, speed, rest pauses, duration effort, frequency of activity period, type o contraction, pattern or single movements, positioning, and concentratior (32,75) Besides these variables, other factors which modify the exercise program used clinically at any given time in the patient's treatment include the duration of inactivity, degree of paralysis and atrophy, type of disability and amount of joint involvement The validity of some of the currently popular techniques of applying strength exercises has been seriously questioned by Hellebrandt and Houtz (32) It was the conclusion of these investigators that the numerous variations in the procedures of administering heavy resistance exercise are almost wholly empirical It would seem that the present day use of strength exercise techniques is based more upon clinical experience and expediency rather than upon research findings

The research in this area is confusing Comparisons of heavy resistance techniques have revealed few differences of statistical significance This appears particularly where there is a common factor of overload It is possible we are wasting considerable time in tedious repetitions where few con

high It may be, however, that the phenomena of isometric and isotonic strength are sufficiently different that the techniques of training to produce improvements should be different Certainly, the seasoned therapist should not change proven technique until the evidence merits it Muller's work should be carefully evaluated and repeated with comparisons made to the dynamic programs of DeLorme and Zinovieff (18,95)

Strength measurements have been employed clinically as indicators of

the rate of recovery from disease or trauma as well as efficacy of treatment techniques and the end point of effective treatment and residual ability (37,45,76,74,89). The clinical evaluation of local and generalized muscle strength includes (1) the single effort test, (2) repetitive effort test, and

ment of tension against a fixed resistance Studies reporting the use of this last type of test are meager The single effort test employed manually seems to be the test universally accepted The technique is commonly known as manual muscle testing (15,45) The perfection of testing techniques to measure strength through the full range of motion both statically and during graded movements would increase our knowledge of functional strength considerably.

The first muscle tests originated in this country about 50 years ago Since this time it is of interest to find that the principles and basic methods of manual muscle-testing remain essentially the same as those developed by Lovett and Wright (57) This type of testing is based on the principles of gravity and resistance Through the years some modifications have been

of assessing paralysis was of critical importance A view of manual muscle testing, its development and current use, with an extensive bibliography has been reported by Williams (94)

Instruments that have been employed for measurement of muscle strength include the dynamometer, electromyograph, tensiometer, myometer strain gage, ergograph, and spring balance scales (37) Clarke has standardized strength testing techniques using the cable tensiometer and presented the objectivity coefficients for these tests (11) Recently published is a report dealing with studies of human strength with particular attention to results of strength tests and relationships between strength and other variables (37) In a recent article the writers questioned the meaning of "strength"

that we will be able to prescribe the appropriate overload to obtain the desired improvement

In the use of functional or achievement tests the objective criterion seems to be the time factor in performing the activity (13,52) The design of functional testing seems to be to determine how many daily activities the patient can perform in his home and in connection with his work This includes such tests as My Score, and Daily Living Skills, (ADL) Activities of Daily Living (13)

The clinical use of these objective measures of strength seems to be based for the most part on empirical evidence There is particular need for longitudinal improvement studies evaluated by various strength measurement techniques for comparison purposes as well as for other quantitative studies to determine the validity of these strength tests Such studies may help shed light upon what is actually involved in the strength tests and furnish further information of the currently popular techniques of exercise

Techniques Used to Improve Range of Motion Clinical procedures

prescribed Exercise, passive and active in some combination, has been particularly effective in conditions of complete denervation, temporary or permanent in preventing or reducing fibrotic and myostatic contractures (44 61) Exercise techniques have been contraindicated in the presence of acute infections, inflammatory processes, muscle spasm, and boney obstructions (44 61) The divergence of opinion and resulting exercise technique seems to be based upon the question of when and how much to stretch in selected disabilities

Exercise techniques recommended for the treatment of peripheral nerve injuries may avoid stretching through the full arc of the movement during the stage of paralysis before re innervation occurs (83) Other exercise techniques approach the problem through daily exercises through the range of movement, and still another recommendation advocates daily movement through full range in the direction of stretching the normal opponents but avoiding full range in the direction that places tension on the weakened muscles (44) The exercise techniques differ not only in terms of stretch or range of movement and direction but also in the number of movements Some advocate one movement daily while others advocate more There

[illegible]
is based upon the clinical experience of the physician and the therapist

There is more general agreement or standardized procedures for stretch

loss of function from transitory types of weakness or paralysis (44) Here again, however, is a lack of quantitative studies to evaluate and compare the efficiency of the clinical techniques employed today

Some interesting material pertaining to indications and contraindications for stretching has been reported by Kendall (1,44) In this report it was postulated that the important factor in determining whether any given

muscles should be stretched and to what extent as well as how should be the distribution of the structural changes within the muscle or muscles regardless of whether the lesions are of circulatory myogenic or neurogenic origin Three questions were raised (1) Can muscle left with healthy muscle in half of its length and the remaining part fibrous tissue withstand stretching through normal range of motion? (2) Can muscle left with half or more of its muscle cells replaced by fibrous tissue in a spotty distribution be expected to stretch to full range of motion? and (3) Can muscle cells undergoing atrophy or degeneration withstand the same amount of tension that can be tolerated by normal muscle cells? These speculations

of motion is used most frequently (63) Such measurements have many purposes the analysis of the patient problem panning of clinical procedures

concept of expression of range in motion Three concepts are present (1) the anatomical position of joints is considered 180 and the figure then decreases through the range of motion (2) the anatomical position is 0° and the figure then increased toward 180° and (3) all basic motions are described on a full circle of 360° in a sagittal plane (63) In order to establish some sort of standard technique the Orthopedic Appliance Atlas has recommended that the anatom cal position be considered zero

The instruments for measuring joint motion as well as methods for recording are extremely diversified The difficulty in the measurements lies principally in reliability The instruments are the single and double goniometers and fleximeters (54 63) with the single and double armed goniometers used most extensively There is evidence that the reliability of goniometer measurements can be increased through the establishment of standardized procedures (63) The Departments of the Army and the Air Force of the United States recently standardized their joint measurement procedures (40) Instruments used in clinical situations are made of all types of material Methods of recording joint measurements are numerous and diversified with sketches diagrams charts photographs stick figures and written measurements in use today (40 63)

Instruments and techniques of recording joint range of motion are extremely important to the field of therapeutic exercise The problems point up the need for serious study in this field The need to study the validity and the reliability of different instruments and specific techniques used in taking joint measurements is readily apparent

Techniques Used to Improve Endurance Generally, clinical techniques for increasing endurance are indirect rather than direct However, there are some exercise procedures aimed at increasing endurance of focal muscle groups According to DeLorme, endurance would result from a program of high repetition and a light load involving the focal muscle group (18) The clinical techniques usually employed for increasing overall bodily endurance utilize graduated activity programs with special attention on the balance and integration of total body function (23,43,82) Exercise programs have been employed for the following clinical conditions cardiovascular, respiratory, and metabolic inadequacy, chronic fatigue, bed rest and immobilization, and deficient functioning resulting from neuromuscular disease or injury However, most of this work has developed in the areas of cardiovascular, tuberculosis, chest surgery, geriatrics and cardiorespiratory poliomyelitis, and general medical care (5,9,14,28,35,64,58,67,82,84)

In clinical use endurance exercise has three different approaches (1) Decrease the energy requirements of an activity by increasing the efficiency of the patient s mechanics in specific desired tasks Specific relaxation procedures may also be considered (2) Redirect the functional goals of the patient by evaluating which activities are essential and which are elective or could be deferred In geriatric patients, for example, small doses of exercise over longer periods of time appears to be most beneficial (5,64) (3) Changing of the energy reserves through reconditioning procedures

The classic work of Leithhauser and the military research on physical reconditioning are examples of the latter approach which has proven to be so striking in the last several decades (58,55) Not only do patients recover faster but there are fewer complications The basis of the program rests in no small part in that deconditioning due to inactivity is reduced, permitting the organic functions to be maintained at levels more conducive to recovery Also the psychological outlook of the patient is better, which points up an interesting area of study—the attitudes of individuals at varying strength and circulatory levels

The physiological principles on which endurance exercise is based are similar if not identical to those encountered in the training and retraining of athletes (23,43) However, problems of patients during convalescence are much more complicated due to the patient's low resistance and the lessening of the regulatory capacities pertaining to circulation, respiration, temperature, and metabolism (23,82) The imposition of endurance exercises [illegible]

cise, blood pressure changes, respiration, color changes, and performance

tests (ADL, Master's Step Test, etc) to guide the therapist With this knowledge his set of exercise principles, often derived empirically, then serves as the basis for the program along with the answers to the following questions How long has the patient been inactive? What are the specific limitations imposed by his illness or injury? What specific and general changes are desired? What exercises would accomplish these objectives best? These and other questions are first answered, then a general estimate of the patient's resistance level is subjectively made The choice of the activity to be used is based on the intensity level desired The energy costs of various activities provides an excellent guide for this purpose Weiss and Karpovich (92) and others have reported such basic information Rate of work, load, skill, and duration should all be taken into consideration The patient is then put to work carefully watched, and the program altered as needed The therapist understands the more overload that can be applied, the faster the recovery, but he also recognizes that if too much is given the patient will retrogress

studies to investigate and evaluate endurance programs used to assist the patient in development of sustained function without harm or injury are essential for future progress It is clear, however, from the research that prolonged bed rest and absence from normal activity can no longer be the "sina qua non" of the treatment of patients suffering from medical and surgical conditions (84)

Techniques for Neuromuscular Reeducation Neuromuscular reeducation is used most frequently to designate treatment procedure for the developing or redeveloping of useful motion patterns in patients with impaired neuromuscular mechanisms as a result of faulty development, trauma, or disease of the central nervous system or the muscle-skeletal system Reeducation of this kind would have application in clinical conditions such as

Neuromuscular reeducation is concerned with applying various physiological principles which can be used for eliciting, reinforcing, and coordinating of muscular movements in patients with impaired neuromuscular mechanisms (75) Any technique employed is used as a means of stimulating and strengthening the response of the remaining neuromuscular mechanism into useful motor patterns

One of the most interesting and effective techniques in this area was introduced by Kabat (42) In the first techniques, great emphasis was placed

on the application of maximal resistance throughout the range of motion, using primitive patterns and postural and righting reflexes Also stretch was applied to groups of muscles and for greater proprioceptive stimulation, motion was performed first in the strongest part of the range of motion Re

and isometric contractions (rhythmic stabilization) had a facilitating effect; and, combinations of motion that proved most effective were spiral diagonal patterns The application of these techniques has been made in gait and self care activities to accelerate the learning process and to improve strength and balance

Other investigations seem to indicate that the afferent impulses play an extremely important role in the initiating of the neuromuscular mechanism eliciting motion and in the reinforcement of volitional effort (10,28, 25,49 57) The use of afferent impulses in neuromuscular reeducation programs is widespread Some reinforcement techniques reported in the training and retraining of patients with neuromuscular disorders include the uses of brush for skin stimulation, cold applications, the use of reflex inhibiting postures and sequence of developmental reflexes, maximal proprioceptive stimulation through resistance, stretch, patterns, associated movements, and postural and righting reflexes, activation of primitive movement patterns and conditioning of basic spinal cord reflexes to achieve useful gross movement, and the use of nociceptive finger bending reflex, the pushing-pulling of joints, tapping, rubbing or squeezing of muscles (7,10,21,49,57,73 75, 86,87)

Clinical application of methods or technique used to elicit, reinforce, or coordinate muscle response seem to be extremely diversified There are no set rules to guide the selection of stimuli or technic employed for a particular patient (10) The selection of the proper stimuli for a particular patient seems to be in terms of the patient s reaction to numerous stimuli If undesirable effects are observed and the progress is limited the stimuli and method of technic is changed The deciding factors in the selection of

the selected stimuli and t
neuromuscular mechanism
the most important (23)
tions would be generally tried first or in conjunction with other stimuli to facilitate volitional activity If this does not succeed then activation of the paralyzed muscles as part response in a reflex pattern or as an associated movement is employed These traces of volitional activity then can be reinforced through the exercise program

It is observed that many of the neuromuscular mechanisms controlling muscle performance show many exceptions or variations in normal persons as well as patients exhibiting pathological conditions, e g, the relation of length of a muscle to volitional excitability of different joint positions which elicit response Other aspects of motor learning that are finding their way into clinical situations and investigations are methods used to augment performance or work capacity These include such things as change in focus of attention, motivation, mental concentration introducing of difficult procedures, variation in performance or exercise procedures, and spacing or spreading of performance or exercise time (2,32 85) It is apparent that the movement potential that exist in neuromuscular reeducation programs is just beginning to be realized Of utmost importance in the progress of this type of program is the gathering of scientific data concerning the use of these various technics in stimulating the still functioning neuromuscular mechanisms into useful motion patterns

One important conclusion that has been reached by workers in this field is that all exercise programs designed for reeducation of the central nervous system have some effect upon the functional condition of the peripheral mechanisms Correspondingly, all exercise programs designed specifically to restore strength, endurances or range of motion bring about some reeducation of the central nervous system All in all, it is increasingly apparent that the whole organism is involved in volitional motor activity and that changes brought about through volitional activity are not as local as they may seem (75)

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CHARLES H McCL

Physical Reconditioning for the

SUMMARY

Prior to the widespread use of physical reconditioning in medicine, t customary procedure was for patients to lie in bed until they were almc ready to return to their homes or, in the armed services, to return to dut Bed rest of this kind resulted in one degree or another of physical deconc tioning and frequently it resulted in an attack of phlebitis and sometim fatal embolism

Physical reconditioning, which received its greatest stimulus to develop ment during World War II, involves having the patient exercise first in be and then later out of bed The benefits of such a program are that the pa tient may return to work in about two thirds the usual time, he does not hav to recuperate as much strength after release, and certain hazards associate with bed rest are reduced

During World War II, the present author was associated with the Depart ment of the Army and was largely responsible for the preparation of a for mulary for the guidance of physicians in their prescriptions of exercise for various types of patients The general objectives of such exercise prescrip tions are (1) to prevent deconditioning (2) to recondition patients whose strength and endurance have been lowered, (3) to strengthen weakened parts, restore range of movement and in general to restore normal function, and (4) to aid in the rejuvenation of the aging Of course, the nature and intensity of exercise must vary, depending upon the type and severity of illness and the response of the patient to the program Under proper conditions results obtained are often striking

General principles governing the use of exercise for the ill include (1) there must be an overload on ... continuous, (3) all exercises used must be beneficial, (4) the

exercises must build strength and muscular endurance, and (5) there should be special exercises for disabilities of individual parts of the body, e g, the chest or the knees

Activities frequently utilized in the reconditioning program include freehand exercise, exercise with dumbbells, barbells and springs, posture exercises, certain gymnasium apparatus activities, medicine ball handling hiking running and informal games sports and aquatics

Although exercise is being used far more extensively in medical practice than it used to be, still there are indications that it is far from being fully exploited as a means of hastening safe patient recovery and increasing the turnover rate of patients in hospitals—with all that this implies for individual well being, financial savings, work output in industry and elsewhere, and availability of medical services

Physical reconditioning is a relatively new field in medicine It received its greatest stimulus to develop during World War II when it was used in the hospitals of the armed services in many countries

Before the use of reconditioning programs in medicine, the generally approved procedure was for the patients to lie in bed until they were almost ready to return to their homes, or, in the case of the armed services, to return to duty They were, after a week or ten days, usually permitted to get out of bed and walk around the hospital This procedure of prolonged bed rest frequently resulted in the patient s suffering an attack of phlebitis, with sometimes fatal attacks of embolism In more recent years two movements have cooperated to avoid this result One is the movement termed early ambulation, in which the patient is gotten out of bed quite early on the second or third day after his operation in surgical cases, and very soon after his fever has returned to normal (or his sedimentation rate has dropped to normal) and encouraged to walk a bit every day The other is this movement of physical reconditioning in which the patient is first exercised in bed, and then later exercised out of bed in some exercise hall connected with the hospital The results of this latter program have been that the patient is usually ready to go back to work in about two thirds the time that would have been taken had he not been given this exercise program, and he is prevented from deconditioning, so that he does not have as much recuperation of strength needed after he is discharged from the hospital This type of procedure is not only important in the armed forces, but it is extremely important in connection with industrial medicine, as it lessens the number of days that the patient is in the hospital, and gets him back to full duty on his job in much quicker time This saves wages for the worker, results in less lost time for the employer, and avoids unnecessary time lost upon the part of professional workers

In the armed services the patients were largely young, and usually the

disabilities were acute In private medical practice and in industrial medicine, as well as in veterans hospitals, there are more and more people of middle and older age and of both sexes, and many of the disabilities are more chronic

In the hospital situation the prescription of exercise must always be made by a physician In many cases this may be the physician who is treating the patient, or it may be a physiatrist, or specialist in physical medicine, who is cooperating with the patient s physician This prescription is not usually made by the doctor in th [illegible]
might write a prescriptio[illegible]
What is meant by this is, [illegible]
used in the hospital in the form of a formulary[1] In the recent World War the writer was one of those in charge of the physical reconditioning of the Department of the Army The first draft of this formulary prepared for the Army hospitals was written by the writer It is called TM 8–292, Physical Reconditioning In a revision of this text, there was another part added, TM 8–294, Advanced Physical Reconditioning This exercise formulary was first written, and then every part of the book was discussed with specialists For example the exercises for patients with disabilities of the heart were discussed with the cardiologists of the Office of the Surgeon General and with cardiologists in several of the Army s hospitals where a considerable amount of experimentation with the program was done The part having to do with general medical treatment was gone over with the specialist in internal medicine at the Office of the Surgeon General, and in hospitals The corrective exercises to be used for individual disabilities, such as an injured shoulder etc, were reviewed, first with specialists from the Department of Physical Therapy of the Office of the Surgeon General, second by the surgeon in charge of Orthopedic Surgery at the Surgeon General s Office, and later at several hospitals Each section of this exercise formulary was prepared in that manner As a result, physicians who were not well acquainted with how to prescribe exercise could with confidence prescribe the exercises given in that formulary

OBJECTIVES OF PHYSICAL RECONDITIONING

The objectives of physical reconditioning are as follows

1 To prevent deconditioning by giving exercise in time to maintain the patient s strength
2 When there has been deconditioning (as would, of course, be true in such illnesses as rheumatic fever and in cases of grave injury), to recondition the patient and bring his strength and endurance back to normal

[1] [illegible] of
the medical staff of the hospital

3 To strengthen weakened parts after the cessation of definitive treatment, to increase range of motion, and in general to help to return to normal function
   a This type of exercise might be used for weakened hearts, as in the case of rheumatic fever after the disease was under control
   b It may be used in cases of poliomyelitis and its residual injury It was also of use in cases of nerve injuries
4 In civilian hospitals and in private practice it is often used to aid in the rejuvenation of the aging

Classification of Patients

Patients are usually classified as bed patients, ambulatory patients, early convalescents, and late convalescents Bed patients are in turn classified under two heads (1) the patient who cannot be permitted to do any exercise (as in acute fevers rheumatic fever, and diseases of that type), and (2) the bed patient who can exercise in bed Deconditioning is always fastest in those who are very ill, and in those who are in great pain and frequently under opiates

Modalities Utilized

The modalities utilized under the area of physical medicine are physical therapy, occupational therapy, and what is here termed physical reconditioning This, in many of the hospitals in the United States, is called corrective therapy This paper deals only with this latter modality Of course, each of the others has its distinctive place, and all three work together for the welfare of the patient

In many cases, particularly with bed patients in private rooms in hospitals, the exercise has to be given individually to one patient at a time This is relatively wasteful of man hours Where possible, patients with the same disability and about the same degree of recovery may be put in the same wards and exercised together in groups Some individual differences may be observed, particularly in the number of executions of each movement done by each patient Certain patients may omit certain movements which would interfere with, for example, the healing of a surgical incision

General Principles

1 The first general principle is that the patient must be exercised to the point where the load on the muscle is in excess of that to which he has been accustomed He makes no progress if there is not a certain amount of overload What would be an overload for a very weak patient would, of course, be much less than what would be an overload for the same patient when he is near complete recovery
2 The progression of exercise must be very gradual but continuous This may be in the form of a more strenuous day s order of activity, or in the form of more executions of each movement

3 It must, of course, be determined that no exercise will be used which will injure the patient All exercises used must be beneficial
4 The purpose of the exercise is to build up his strength and his muscular endurance For war and for sports, circulorespiratory endurance is also taken into consideration during advanced reconditioning
5 There will be special exercises of a remedial nature for disabilities of individual parts of the body, such as injured shoulders, injured knees, the chest following operations on the lungs, and conditions of that nature

In considering the matter of the overload principle, it has been found that exercises that utilize up to about two thirds of the maximum strength of the muscle is much more useful than exercise with smaller dosages To illustrate, the writer can flex his forearm with a dumbbell of approximately 50 pounds in his hand If the writer were to wish to strengthen the muscles which flex the forearm, and were to exercise with a weight of only 10 pounds in his hand, he might develop some muscular endurance, but the exercise would have almost no effect upon the development of strength The reason is that the muscle is already much stronger than is needed to flex the forearm with 10 pounds in the hand If, on the other hand, he were to first flex the forearm with a weight of about 20 pounds in his hand, and do the exercise perhaps 10 or 12 times as a warm up, and were then to do the exercise with about 35 or 40 pounds and do it as many times as possible, the muscle would grow in strength quite rapidly, usually as much as 3 to 5 percent per week The weight would have to be increased, of course, as the muscles improved in strength

Recently the work of Hettinger and Muller (1) has indicated that it may be possible to increase strength at about the rate indicated by simply holding one isometric contraction with two thirds of the maximum weight that can be lifted, and holding the contraction for six seconds More work needs to be done on this type of exercise to determine its effect on endurance as well as on strength It is, however, a type of exercise that can well be used with individuals who cannot with safety engage in other types of exercise For example, it may be used in the hospital bed when the exercises of each part of the body are separated by 5 or 10 minutes, in cases of coronary occlusion of a minor type, and in many other disabilities of heart, or sometimes of the nervous system when other forms of exercise might be extremely dangerous

Later work by Muller indicates that one contraction held only momentarily, if two thirds of the maximum strength is exerted, is sufficient, it need not be held six seconds (3)

Exercises in Connection with Surgical Operations

It should be remembered that the surgical patient is practically normal except for the part that has been operated on For example, an individual

whose gall bladder has been removed is normal as to legs, back, chest, shoulders, arms, and neck, but has had certain muscles in his abdomen severed He can, if the exercises are well chosen, begin exercising the next day if he exercises only the parts that are still normal He may begin, of course, only when his surgeon so indicates In general, certain precautions must be taken First, he should keep his glottis open so that there is no undue intrathoracic or intra abdominal pressure This will do a great deal to prevent any sutures from being ruptured Second, he must not do any jumping so that there might be what is sometimes called a "water hammer effect It will be remembered that the viscera are about 90 percent water, and hence a viscus such as the small intestine, which has been repaired, is really ' floating' in a ' pool" of abdominal viscera that are 90 percent water If there is no jarring and no undue straining by closing of the glottis or by too much bending, exercise may be engaged in with safety long before these parts are completely healed In general, the chest should be kept high and not carried downward in such surgical cases where the surgery is of the chest or abdomen This, of course, is not imperative in surgery of the arms and shoulders or legs

For some reason there is a transfer of exercise effect from the nonoperated parts to the operated parts For example, a man who has his right lower leg in a cast will have the muscles of that leg improved somewhat, or at least deconditioned much slower if other parts of the body are used The author disclaims knowledge for the cause of this transfer of exercise effect, but we have repeatedly demonstrated it in the author's laboratory, and in other laboratories as well It must be stated that other experimenters deny this phenomenon

Exercise for the Medical Patient

Again, the exercise is never to be begun until it is prescribed by the physician Usually it has been found that the exercise can with profit begin as soon as the sedimentation rate is approximately normal This is usually about 24 to 48 hours after the temperature has become normal This, of course, is not true in such disabilities as rheumatic fever The results of such exercise programs are quite striking In one experiment conducted in an Air Force hospital near St Louis during the war, 300 cases of virus pneumonia who were given the exercise treatment were contrasted with 300 who were not exercised Exercises were begun as soon as the sedimentation rate was approximately normal, and, as stated above, this was usually about 24 hours after the fever was normal These individuals first exercised only about 15 minutes and very gently The next day they extended the amount of exercises Gradually, exercise was increased to as much as four hours per day, about three hours of it being rather nonstrenuous play

The exercised groups were in the hospital a total of an average of 31 days before returning to duty The nonexercised groups were in the hospital an

average of 45 days before returning to duty The exercised patients had a relapse rate of 3 percent, and the nonexercised patients a relapse rate of 30 percent This would seem to indicate some of the values of such exercise programs

The exercise must, of course, be begun gradually, and progress made in accordance with the condition of the patient and how he stands it In heart disease cases, the patient is usually exercised at first only while lying down, and the progress is very gradual It is surprising, however, how rapidly he can progress under a well worked out program This exercise program is also used in connection with the principle of getting the patient out of bed and walking around the ward and around the hospital as early as possible, and keeping the amount of exercise within his tolerance

As stated above in many cases this exercise can be done with groups of patients and need not always be prescribed individually This has good psychotherapeutic results The patient works better when he is working with others This does not mean of course that the exercise program is all the same for everyone For example, certain individuals may be told that they stop on the sixth execution of a movement Others may be told to stop on the 8th execution, and some as high as the 16th Some are told that they may not do certain exercises, while others may do those exercises

Where there have been nerve injuries or something of that kind, the individual corrective exercise is also prescribed

A group of collaborators have published elsewhere (4) some of the best forms of treatment for the neuropsychiatric patient Since that would be a chapter all by itself it will not be discussed further here We may say, however, that this type of treatment has been found in the United States to be a most valuable form of treatment for the neuropsychiatric patient

Types of Activities

The types of activities that have been most used in reconditioning programs with which the author has been connected have been those of free hand exercise or exercises with dumbbells, barbells, springs, etc, and these may all be used either with bed patients, ambulatory patients, or convalescent patients Posture exercises are frequently used With advanced convalescents apparatus may be used from time to time, particularly pulley weights, stall bars, and other forms of gymnastic apparatus A good deal of hiking, and later running, is used The various types of therapeutic apparatus usually used by physical therapists is, of course, also indicated The medi

The Corrective Program

With the corrective program, a great deal of work can be done for parts of the body that have been injured, and much may be done without apparatus

Where apparatus, such as shoulder wheels, and various methods of putting an overload on individual parts of the body are available (as they frequently

A few miscellaneous observations may be in order A good deal of emphasis has been placed in Army hospitals in the United States on the training of patients to use a prosthesis This is, of course, the program done with amputees and is a special type of reconditioning of its own

The stretching of fasciae is also important in cases where there has been limitation of movement The patient is also frequently taught to relax in order to get more rest

At the beginning of exercise, particularly for those who are overweight, in all knee bending, the heels are kept on the floor This reduces the strain on the posterior cruciate ligament, and later as these ligaments strengthen, the individual may do the usual knee bending with the trunk erect and the heels raised

It is usually also wise not to do forward bending with weights in the hands to too great an extent A partial bend will exercise the back without straining the sacroiliac joint Overweight patients should, of course, be reduced

One could go on discussing the matter of tests to be used and things of that kind These tests, however, are described in considerable detail in text books that are now available (2) Other tests of a circulorespiratory nature (2, sections 490 and 496) may be used to determine when patients may increase the amount of exercise

It has come to the attention of many persons that exercise therapy programs, particularly in the Armed Forces, have been largely discontinued When the officers in charge of professional services are asked about this, the usual answer is that during peacetime there is no hurry There are enough nurses and physicians in the hospitals to take care of all of the patients, and there is no need to accelerate the convalescence This, to the writer, is an indication of the practice of third-class medicine If a physician does not know any better and handles his patient with outmoded treatment, it can be called second-class medicine But where he knows better, it is difficult to call it anything better than third-class medicine

For example, a physician who has treated typical pneumonia, not with appropriate antibiotics, but with just good nursing and prayer, would hardly be called a competent physician A patient treated for lues with salvarsan and some bismuth remedy, rather than with the best of today s remedies, might well be sued for malpractice

The writer, when studying in Johns Hopkins Medical College, from 1911 to 1913 (at that time, there was no postgraduate work available in physical education, and the writer chose to study for two years in the basic medical sciences), remembers that, in internal medicine, Drs Barker and Thayer of that institution both emphasized the fact that every patient should be

treated so that he could recover as fast as possible When physicians, knowing the benefits of exercise therapy, choose not to utilize it, and thus slow up the patient s recovery, and even in some cases by taking chances on the occurrence of phlebitis with resulting embolism through lack of activity which endanger the patients lives, in the light of what we know about the benefits of exercise therapy, it is hard to excuse such neglect

In conclusion, the author would like to state his belief that this type of program will some day be standard procedure in every civilian and military hospital It will save perhaps 20 to 50 percent of the hospital days, and will usually save at least a third of the time between the onset of illness and the time when an individual may be back to a full work program The cost will be negligible For example, suppose a patient is in the hospital for 10 days with a hospital room cost of $9 00 per day—and he is without exercise He would undoubtedly be able to go home at the end of his sixth day if he has been adequately exercised *This would be a saving of $36 00, and certainly* the cost of the exercise therapist would not be nearly that amount when his services are distributed over a large number of patients in the hospital So it is actually an economical movement It is suggested by the author *that organizations interested in sports medicine and organizations interested* in hospital practice in general give much attention to the preparation of exercise formularies of the kind indicated and extension of this treatment not only to hospital cases, but to convalescent cases who are normally treated at home They can be taught home exercise programs to use by themselves, or be taught by a visiting reconditioning specialist, and they can also go to private gymnasiums for a short course of such exercise during early convalescence

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EMMA LAYMAN

Physical Activity as a Psychiatric Adjunct

SUMMARY

For many years physical recreation has had a place in the program of the psychiatric hospital, but prior to World War II it was usually included for its diversional value only. Since the war the concept of individually prescribed exercise as "therapy" has gained widespread acceptance, and it has been hailed as one of the most valuable adjuncts to psychiatric treatment. Usually it is presented as "recreation therapy," "corrective therapy," or both.

Prescription of physical exercise for the treatment of hospitalized mental patients is based on an understanding of the needs of individual patients and a knowledge of the psychodynamics of different kinds of exercise. Special attention is given to forms of exercise which have potentialities for encouraging self-expression, promoting communication, developing socialized habits and attitudes, increasing the range of interests, improving self-confidence, motivating the patient to return to reality, gratifying narcissistic needs, expiating feelings of guilt, and facilitating relaxation. These exercises are planned on the basis of a prescription made by the physiatrist and psychiatrist. Behavior patterns and verbalizations of patients are noted by the physical education therapist (recreation therapist or corrective therapist) and recorded, providing information about the patient which may be effectively used by the psychotherapist. Where used, physical exercise therapy is one of the adjunctive therapies employed in a "total push" program to rehabilitate the psychiatric patient, with the program including such varied approaches as psychotherapy, shock therapy, chemotherapy, bibliotherapy, occupational therapy, physiotherapy, educational therapy, and recreational therapy. It is emphasized that physical exercise therapy is therapy through *exercise rather than therapy* by *exercise.*

Corrective therapists, recreation therapists, and psychiatrists have given

glowing reports of the effectiveness of individually prescribed exercise in promoting improvement in hospitalized patients—particularly in schizophrenic patients who have been hospitalized over long periods and have not responded to other therapies There seems no doubt that it does promote improvement However, most of the reports are not based on controlled studies, but on the before and after' observations of persons who in some instances may not be too objective in their evaluations Some progress has been made in developing rating scales and other evaluative measures but these have not yet been used extensively for research purposes Some of the studies showing significant changes taking place in patients after participation in a program of physical activity are such as to make it impossible to rule out the chance that these changes might have resulted from some other kind of therapy, or from the overall total push' program, since the other therapies are not controlled in most of these studies A few studies have utilized control groups and a research design of such a nature as to make the findings of scientific validity Among these are studies by Meyer (recreation therapy, 40), Van Fleet (physical education therapy, 55), Timmerman (swimming, 53), and Kramer and Bauer (swimming, 31) Although the findings of Kramer and Bauer are somewhat equivocal, the studies as a whole point to the beneficial effects of physical exercise in improving the adjustment of hospitalized psychiatric patients These findings are supported by a

controls

USE OF PHYSICAL ACTIVITY IN TREATMENT OF PSYCHIATRIC PATIENTS

Sports and other physical activities have long been included in the programs of most psychiatric hospitals, but originally they were considered as primarily diversional in nature—organized chiefly to help counteract the monotony of mental hospital life and to give the patients something to which they might look ... the

prescribed in terms of disease entity and individual needs had been given some recognition, and the term "recreation therapy' had come into use (6)

Before World War II, however in most psychiatric hospitals physical education was principally on a group and diversional level

World War II gave impetus to the development of programs of physical reconditioning in military hospitals, although the discriminating use of physical exercise in the rehabilitation of psychiatric patients was not extensive in military hospitals until the Korean conflict After World War II the Veterans' Administration took the lead in developing concepts and procedures of physical reconditioning, with considerable work being done in the use of individually prescribed physical exercise as an aid in the physical, psychological, social, and vocational rehabilitation of the neuropsychiatric patient The term corrective therapy was selected to designate such individually prescribed exercise programs, whether in general hospitals or psychiatric hospitals In mental hospitals today, such exercise therapy is common Exercise prescribed for rehabilitation may be in the context of recreational therapy, corrective therapy, or both Whatever it is called, however, it is based on an understanding of the specific needs of the individual patient

DEVELOPMENT OF MODERN CONCEPTS OF PSYCHIATRIC TREATMENT

Psychiatry of the 1920 s tended to resign itself to the idea that a large segment of the population of any mental hospital would always consist of patients who could not be rehabilitated, who would not respond to therapy, who would become more regressed and deteriorated, and who eventually would exist on an essentially vegetative level The development of new techniques of shock therapy, chemotherapy, psychotherapy and psychosurgery began to change the picture, so that many patients formerly considered 'hopeless' began returning to their homes and made fairly adequate adjustments As this was going on, developments in occupational therapy, educational therapy, recreational therapy, and corrective therapy were such that these came to be recognized as extremely valuable adjuncts to the psychiatric therapies, increasing the effectiveness of other approaches to therapy as well as having therapeutic results in their own right

The present day concept of treatment in the more modern psychiatric hospitals is the total push concept, in which every patient is treated by means of that particular combination of therapies which is most appropriate for meeting his needs—in which his total experience in the hospital milieu is therapeutically oriented, although his contacts with the psychiatrist may be limited Thus despite continued shortages among psychiatric and adjunctive personnel, patients are being constructively treated who in the old days would have been left to vegetate, or who would have been confined to padded cells The result of this has been the creation of an entirely different atmosphere in the mental hospital, the opening up of some of the closed wards, and release of many patients

ESSENTIALS FOR A PROGRAM OF EXERCISE THERAPY

Those who originally envisaged physical education as a therapeutic adjunct for use with psychiatric patients and have developed the techniques of recreation therapy and corrective therapy have been guided by a knowledge of developmental psychology, symptomatology, and psychodynamics of different types of mental illness, psychology of play and recreation, principles of psychotherapy, essentials of body mechanics, and the mental health potentials and dynamics of different physical education activities On the basis of such knowledge, the following conditions have been postulated as essential for the success of exercise therapy

1 *It should be on the basis of combined direction and supervision by a psychiatrist and a physiatrist*

2 *It must be carried out by an adequately qualified staff of therapists* Qualifications for the recreational or corrective therapist in a psychiatric hospital include not only professional training in physical education but training in abnormal psychology and psychodynamics, and personality characteristics of such a nature that he can readily form a therapeutic relationship with the psychiatric patient Davis describes the effectiveness of the corrective therapist as depending on "(a) practical knowledge of the patient's personality, his interests and motivational areas, (b) an understanding of his physical and psychological potentials, (c) an appreciation of the uniqueness of modified and motivated physical exercise as a vehicle for interpersonal relationships, (d) his skill in techniques" (14,17)

3 *It must be based on a prescription for each patient, with this prescription being determined by the patient's highly personalized individual needs* The literature on corrective therapy and recreational therapy includes classifications of activit ... nd approaches suitable for patie ... 2,15,23,29,43) Greenwood (23) ... disease entiti alone, however, is not enough, and that psychiatric patients "need to be

... the

4 *It must be a part of a more comprehensive treatment program, and provide information about the patients which may be used constructively by other therapists—especially psychotherapists*

Nature of the Patient Therapist Relationship

It has been repeatedly stressed that two factors are of importance in any kind of activity therapy—the therapist and the activity program Of the two, *the therapist is more important than the activities, and the nature of the interpersonal relationship between patient and therapist is the principal factor* determining the success of the therapeutic program (14,23,37,45 47) Some of the characteristics of the therapist who is able to establish emotional rapport with patients are described by Reagan as follows

"1 Your language or finesse and cleverness of expression is not as important as your sincerity and emotional strength

2 *Your role should be that of the protecting mother, not the castrating father*

3 You must be absolutely and genuinely free of defensiveness

4 Your attitude should be forceful and benignly aggressive, but not one that conveys anger, irritability or impatience It should be rather the kind of

discussed For example, Greenwood (23) suggests that, because the depressed patient has a need for punishment, the therapist should maintain an attitude of severe kindness, and avoid too much sympathy Jenkins (26), discussing work with withdrawn catatonic patients, points out that 'an approach which embodies gentle, patient, persistent, and consistent effort toward diminishing muscular tension and establishing confidence in the interpersonal relationship results in a gradual development of human response and a gradual freeing, for adaptive behavior, of the frozen personal resources" (26,204)

Rationale for Use of Physical Activity as a Therapeutic Medium

The rationale for use of physical activity as a therapeutic medium is based on an understanding of the characteristics and needs of psychiatric patients, and a knowledge of the psychodynamic significance of physical activity

CHARACTERISTICS OF PATIENTS WITH PSYCHIATRIC DISORDERS

Abnormal reaction patterns have been classified in the following groups (1) Transient personality reactions to acute or special stress, (2) psychoneurotic disorders, (3) psychoses without known organic etiology, (4) mental disorders with toxic or organic brain pathology, (5) character and behavior disorders, (6) alcoholism and drug addiction, and (7) disorders of intelligence (8)

Transient personality reactions are those in which symptoms of personality decompensation have been precipitated by great or unusual stress such as that associated with accidents, fires, unusual and trying life situations, or combat fatigue. Persons in this category are essentially normal individuals who have 'broken down' as the result of shock or strain. They may temporarily present symptoms of neurosis or psychosis, but readily recover with psychotherapy, rest, and sedation. Activities included in a treatment program for these patients are for purposes of helping to promote interest and enthusiasm and to encourage in the patients the idea that they are 'well.'

Psychoneurotic disorders are abnormal behavior patterns resulting from persistent mental conflicts. There is no gross disorganization of the personality and no loss of contact with reality, so the neurotic patient ordinarily can be treated in an out-patient setting. The chief characteristic of the neurotic is anxiety, which he attempts to control by use of various defense mechanisms. Other characteristics of the neurotic patient are hypersensitivity, egocentricity, emotional immaturity, somatic complaints, general dissatisfaction and unhappiness. Although these characteristics are in all neurotics to some degree, there are various kinds of neuroses, each characterized by a particular type of symptom syndrome. No attempt will be made to delineate these syndromes, but it should be noted that neurotic symptoms may include such widely varying patterns as complaints of fatigue, paralysis of psychogenic origin, amnesia, phobias, prolonged dejection and discouragement, and irrational thoughts and impulses which the individual recognizes as irrational. Neurotic disorders almost always show a long developmental history, usually having their source in faulty parent-child relations. Treatment for the neurotic involves (1) helping him to understand the dynamic significance of his symptoms and (2) helping him to find more adequate means of dealing with his problems. The principal form of therapy is psychotherapy, but various adjunctive therapies such as bibliotherapy, occupational therapy, and recreational therapy may contribute toward the acquisition of insight, reduction of anxiety, increase in confidence, and development of more constructive patterns of living.

Psychoses are abnormal behavior patterns involving varying degrees of personality disorganization with loss of adequate contact with reality. For psychotic patients, hospitalization usually is required. Psychoses may result from brain pathology or may be without known organic etiology.

The *functional psychoses* include three groups of disorders—schizophrenic disorders, paranoid disorders, and affective disorders. The principal characteristics of schizophrenic disorders are emotional 'blunting," retreat from reality, and disturbances in thought processes. Four types of schizophrenic reaction have been described. The *simple type* of schizophrenia is characterized by apathy and indifference, with no conspicuous delusions or hallucinations. The *hebephrenic type* is recognized by severe disorganization, silliness, peculiar mannerisms, delusions, and hallucinations. The *catatonic*

type has prominent motor symptoms—either generalized inhibition often to the point of stupor, or excessive motor activity and excitement The *paranoid type* is usually hostile and aggressive, and has poorly systematized delusions

The paranoid disorders are marked by persistent delusions, but without general personality disorganization These include the paranoid state and paranoia The paranoid state is characterized by transient and rather poorly systematized delusions, but without the other distorted thought processes of the schizophrenic Paranoia is a condition in which there are well systematized delusions of persecution and/or grandeur The conditions diagnosed as paranoid disorders are not common in the hospital setting, and in most references to "paranoid patients," it is paranoid schizophrenia which is meant In fact, many psychiatrists contend that there are no paranoid patients without characteristics of schizophrenia

The affective psychoses are those in which the most prominent manifestation is extreme mood fluctuation, with accompanying thought disturbances The *manic depressive* type of psychosis is characterized by prolonged periods of excitement and overactivity or by periods of depression and underactivity, by alternation from one phase to the other, or by mixed symptoms—e g, depression with hyperactivity ("agitated depression") In the *psychotic depressive reaction* the patient has delusions of guilt and worthlessness, and severe depression *Involutional melancholia* is a psychotic depression associated with climacteric changes, with the patient usually being quite agitated and apprehensive

Schizophrenic like symptoms or mood disturbances may be associated with organic brain pathology, due to factors such as infection, head injury, tumors, metabolic or endocrine disturbances, intoxication, cerebral arteriosclerosis, and senile deterioration

Literature on treatment programs for psychotic patients frequently describes groups of patients as "acute," "chronic," "retarded," or "regressed" Those described as "acute" are usually the ones who are hyperkinetic, agitated, and perhaps assaultive They may include manic patients, agitated depressives, hebephrenic schizophrenics, and some catatonic, paranoid, and "mixed" schizophrenics The "chronics" are usually relatively inactive patients with diagnoses of simple schizophrenia, catatonic schizophrenia, depression, or various of the organic psychoses The "retarded" are the hypokinetic patients, and the "regressed" are those who have retreated from reality to the point where they have abandoned all civilized adult behavior patterns and may be conducting themselves more like animals than like people A variety of exercise programs have been used effectively with each of these groups of psychotic patients, with an effort being made to restore them to a normal "tempo," to make it possible for them to communicate and live cooperatively with people, and to motivate them to return to contact with reality and responsible functioning

The *character and behavior disorders* are characterized by life long patter

of 'acting out" rather than a personality decompensation following excessive stress They include *immaturity reactions* and *pathological personality types* Alcoholism and drug addiction tends to occur in rather immature individuals

Disorders of intelligence include *primary mental deficiency* (present since birth and without known pathology), and *secondary mental deficiency* (resulting from organic brain damage)

In military hospitals, patients with psychoneurotic disorders, character and behavior disorders, and transient personality reactions are common on the psychiatric wards, but do not remain there long These patients are usually studied in the hospital and then returned to duty (perhaps with outpatient treatment being arranged), or are released from military service Psychotics treated in military hospitals are in the early stages of psychosis, and those who remain for treatment are the ones for whom the prognosis is good In civilian hospitals, the majority of the patients are psychotic Many are chronic, deteriorated, regressed psychotics, or senile patients Most of the experimentation and research on the uses of exercise therapy has involved its use with psychotic patients, although some attention has been given to its use with neurotics (43)

NEUROMUSCULAR CHANGES IN PSYCHIATRIC DISORDERS

Greenwood (23) points out that from before birth, every human being requires muscular activity in order to develop properly For the young child, muscular movement is a source of pleasure and plays an important role in

from his personality development If this concept has validity, it would be expected that in the psychiatric patient there would be motor dysfunction, and that a therapeutic approach through motor activities would result in psychological changes

Describing psychiatric patients in terms of their neuromuscular characteristics, Greenwood (23) designates them as *hyperkinetic*, *hypokinetic*, and *parakinetic* The hyperkinetic, exemplified by the manic, has increased muscle tone, and short reaction time He is quick, aggressive, and perhaps destructive The hypokinetic has low metabolism, a paucity of ideas, poor posture He is limp, slow in movements, sometimes stuporous In this group are the depressed and catatonic patients The parakinetics are the schizophrenics, whose actions do not fit the stimulus Their behavior may be stereotyped, negativistic, paradoxical The kinetic deviations in the neurotic differ from those of the psychotic only in degree Recognizing the psychokinetic aspects of psychiatric disorders, Greenwood suggests that one adjunct to psychiatric treatment should be a kinetotherapeutic approach

PSYCHODYNAMICS OF PHYSICAL ACTIVITY

Those arguing for the value of exercise in the rehabilitation of psychiatric patients have called attention to the following psychodynamic characteristics or properties of physical activity

1 Physical exercise helps to develop and maintain optimum physical condition in the patient *Thus it not only should give him the physical stamina* which he needs before he can resume normal work functions in the community, but would be expected to contribute to a feeling of well being and self-confidence (21,47,56)

2 Exercise encourages release of energy and induces natural fatigue (56), with relaxation following exercise (47) so that the need for sedation and restraints for hyperkinetic patients should be reduced

3 *Learning control of the body is helpful in learning control in other* areas (15)

4 Physical exercise is a medium for self expression *(1 15,23,29,37,42,50)* Because it is perhaps the earliest form of self expression, it provides a means by which even the most regressed schizophrenic patient should be able to express himself (42) Activities such as the dance are adaptable for expression of various feelings, and activities such as competitive sports, kicking, hitting a golf ball, and striking a punching bag are particularly useful for channeling or sublimating aggressive impulses

5 Because physical activity is a medium of self expression it also is a means of communicating feelings and character traits (36,42,47) Thus the patient communicates to the observer his conflicts and reaction patterns, and knowledge about the patient, thus obtained, may be effectively utilized in psychotherapy (15,21 36,51)

6 Physical activity in the play situation is associated with the more pleasant experiences of childhood and tends to be repeated by the patient under *appropriate stimulus* (4) *Thus it is an appropriate approach for arousing* interest and to elicit response in a disinterested, inactive patient (13,56)

7 Certain types of exercise—especially those which afford opportunities for display of strength, skill, and grace to admiring companions—lend themselves to satisfying the need for narcissistic gratification (23,29) In certain types of psychiatric patients—*especially* paranoids—satisfying this need is necessary before the patient can acquire more socialized attitudes

8 Some forms of exercise—*particularly those presented routinely* and monotonously—may serve as a means of expiating guilt in the patient who has a need for self punishment (23,29 46)

9 Physical education activities provide experiences with concrete objects and hence provide reality testing experiences which would seem to encourage reestablishment of contact with reality in the psychotic patient (18,46)

10 Various characteristics of a physical education program point toward its potentialities for resocialization of the withdrawn, regressed patient (13,18,21,25,47) The emotional climate and cooperative activity involved in team play encourage the development of responsibility and good interper

velopment of the ability to relate to people

11 Physical education activity is goal directed activity As stated by Jenkins (25), 'Goal directed activities are the chief means for strengthening the ego Successful goal-directed activity is the chief basis for self confidence, and it is goal direction which is largely responsible for intelligent self control and self discipline" (p 24) The schizophrenic patient is lacking in well defined goals and lacks resourcefulness in the pursuit of such goals as he possesses Organized, goal directed physical education activities should be able to help the patient to become goal oriented

STUDIES SHOWING THE EFFECTS OF PHYSICAL EXERCISE ON THE PERSONALITY CHARACTERISTICS OF PSYCHIATRIC PATIENTS

Like most therapeutic approaches, the physical exercise approach to the treatment of psychiatric patients has been developed largely on an empirical basis Psychiatrists, physiatrists, and physical educators have reasoned that certain techniques ought to work with certain types of patients and so have tried them out If the techniques or activities have seemed effective, these have been incorporated in the rehabilitation program Since there is an understandable reluctance to deprive any patient of any type of treatment which might benefit him, the research dealing with the effects of exercise on the adjustment of psychiatric patients until recently has been largely of the type usually employed in preliminary studies, with relatively few research projects comparing the effects of different kinds of activities or employing control groups

Those who have been involved in the development of corrective therapy programs or who have had contact with such programs in advisory or administrative capacities have reported very encouraging results (20,21,24,26, 28,41,46,55) Their reports have been based not only on behavioral observations made by ward personnel, but also on statistics showing a reduction in the need for other types of treatment (28,29) Although there is no doubt that exercise therapy *is* beneficial to psychiatric patients, it is possible that some of the observers evaluating the effects of this therapy have not been completely unbiased Also, since it is rare for a psychiatric patient to receive *only* physical education therapy, in many studies it is difficult to tell what

changes are due to the effects of the physical rehabilitation program and what ones are the result of other therapeutic approaches used in the "total push" program

The following have been among the results attributed to the effects of participation in physical activity improved physical condition (46), relaxation and reduced hyperactivity in "acute" patients following exercise (29,46), a feeling of adequacy, confidence, or self esteem (13,34,36), greater cooperation, identification with group values, and conformity to conventional social practices (6,40), more disciplined aggression (13), improved contact with reality (17,18), greater emotional control (6), increased range of interests (6), stronger volition (6), increased insight (6,36), and improved spontaneity (2,18)

Typical of the usual approach to studying the effects of exercise on the psychiatric patient is a study by Marusak (37) He reported on the effects of corrective therapy on 49 chronic and acutely disturbed psychotic patients, many of them being schizophrenic These were patients who were unable to participate in other hospital activities because of their uncontrolled, disturbed behavior patterns, or who, if assigned to other activities, took an apathetic attitude toward them The most common trait characterizing these patients was combativeness, with destructiveness and unpredictable behavior being frequent Before the corrective therapy program was instituted, extensive use of hydrotherapy was necessary

In Marusak's study the treatment aims were to provide a socially acceptable method for expression of aggression and to promote an increase in social participation The prescription of activities was made on the basis of the patient's operating level The typical procedure was to start with the striking bag, then have basket shooting, and finally socialized activities Praise and encouragement were given, to make the activity period a satisfying experience All of the patients received tonic hydrotherapy at the end of each corrective therapy session After institution of the program the ward as a whole became much quieter and the number of altercations diminished Several patients who had been assigned to other activities, but were apathetic toward them, began to show more interest There was a reduction in the number of hydrotherapy treatments, with more being needed on nontreatment days than on days when the patients had corrective therapy On the basis of observations, it was felt that the program was of value in channeling aggression, improving socialization, increasing communication, and providing additional information about patients which was diagnostically useful The staff was of the opinion that emotional rapport between patients and therapist was of primary importance in attaining these results In discussing the results of the program Marusak states In the absence of a control group, it is not possible to say with assurance that all the improvement reported is due to the corrective therapy technique However, it is the impression of the professional staff that the reported improvement is largely, if not

altogether, the result of the corrective therapy treatment program" (37,10)

Meyer (40) studied the influence of participation in prescribed recreational activities on the behavior of schizophrenic patients. Although the activities in which patients participated did not all involve physical exercise, athletic activities had a prominent place in the program. Hence, this study seems pertinent to the effect of athletics on behavioral changes in psychiatric patients.

The purposes of Meyer's study were (1) to determine whether prescribed active participation in recreation can influence the behavior of long term, chronic, inactive schizophrenic patients and (2) to determine whether prescription of activities based on premorbid participation experiences is more beneficial than prescription of activities based on no premorbid participation experience.

The cases studied by Meyer included 202 schizophrenic patients in a Veterans' Administration hospital. All had been hospitalized for many years and none had shown any significant psychiatric improvement through the years. For each of the patients a history of premorbid recreation participation was obtained through a questionnaire mailed to the next of kin, with additional information being obtained from social service and clinical records. Each patient was rated on the Montrose Behavior Rating Scale and an individual profile established. Sixty six perfect sets of "threes" were matched for two experimental groups and one control group of twenty patients each, with six sets held in reserve. The three groups lived together for the duration of the experimental period and followed identical routines except for the single variable of active participation in recreation activities. The first experimental group engaged in a program of three active participation recreation activities from their premorbid experience, from 1:00 to 4:00 P.M. daily for six months. The second experimental group spent the time engaging in active participation recreation experiences which were not included in the premorbid participation histories. The control group remained in the day room while the others were engaging in active recreational activities. After three months and after six months the Montrose Behavior Rating Scale was again administered. Statistical analysis of the data showed that significant changes in behavior took place in all three groups in the course of the experiment and there were significant differences between the groups. The results led to the following conclusions: "(a) Active participation in recreation activities by schizophrenic patients will result in a favorable change in their behavior. (b) Schizophrenic patients not given recreation activities will have an unfavorable change in their behavior. (c) Active participation in recreation activities based on premorbid participation experience will be more beneficial than active participation based on no premorbid participation experience, after three months, but not after six months" (40,3)

Van Fleet (55) studied the influence of physical education therapy on the personality characteristics of chronic schizophrenic female patients in a state mental hospital Ninety four patients were matched by pairs on the variables of type of schizophrenia, age, and length of hospitalization The 47 matched pairs were further equated by groups on the basis of ward location and scores on the Healy Pictorial Completion Test II The experimental group participated in a physical education therapy program twice a week for a period of six months, while the control group continued with the regular hospital routine Changes in behavioral characteristics were measured on the basis of the following criteria (1) Scores on Healy Pictorial Completion Test II, (2) Scores on Wechsler Bellevue Adult Intelligence Scale (4 subtests), (3) carriage ratings (from posture photographs), (4) changes in drawing of a person, (5) behavior records based on observations made during therapy and on the ward and (6) quarterly notes written by the ward physician All of the comparisons made between the experimental and control groups showed significant differences between the groups, with improvement in behavioral characteristics being found in the experimental group Van Fleet [illegible]

"(a) The opportunity for members of the experimental group to be identified with a selected therapy group

"(b) The opportunity for members of the experimental group to be roused from their autistic environment on the ward and to be brought into frequent contact with reality situations

"(c) An awareness on the part of some members of the control group that other patients had the opportunity of participating in a selected therapy group

"(d) The opportunity for each member of the experimental group to respond according to her capacity in a permissive, nonthreatening environment

"(e) The capacity of the therapist to maintain a consistent frame of reference that gave opportunity for progressive success on the part of the patient" (55,76–77)

Some studies have focused on the effects of specific kinds of activity on the personality characteristics of psychiatric patients Among the activities receiving some special attention are dancing, swimming, and weight lifting

Dance Therapy

It has been pointed out that the dance, as a means of expressing and communicating the characteristics of both the individual and the culture, has been practiced in some form in every society since the beginning of recorded history (35) It has been held, also, that nonverbal communication preceded

verbal communication in man's phylogenetic development (7), and that self expression through rhythmic movement "appears to fulfill deeply rooted, universal urges in men to express themselves" (35,176) Observation of young children indicates that they have a tendency to express themselves spontaneously through movement, in response to rhythmic stimuli, and continue to do so until the acquisition of language causes words to replace movement as the favored medium for expression and communication, and until awareness of the evaluative judgments of others causes them to become self conscious about their movements

Because the psychotic has difficulty in using language for communication, and because the dance involves nonverbal expression of emotion, dancing would seem to offer promising possibilities for treatment of the mentally ill Several studies have reported its successful use as an adjuvant to psychiatric treatment, with a variety of patients (2,3,19,27,35,38,49)

Bender and Boas (3) used the dance in a treatment program for a group of children on a psychiatric ward, with the children representing all types of behavior disorders and psychiatric problems Flaherty and his associates (19) tried dance therapy with a group of regressed schizophrenics Martin and Beaver (35) used it in the out patient treatment of schizophrenics in remission, with the patients being ones who had been resistive to other forms of group therapy Rosen (49) has experimented in use of the dance in the treatment of various psychotics, as have Chace (7), Jurcisin (27), and May (38) Bainbridge and co workers (2) report its use with both neurotic and psychotic patients Feber (17), although working chiefly with the physically handicapped, has found the dance especially useful with those whose physical ailments are at least partially on a psychosomatic basis

For many years social dancing has been included in the programs of psychiatric hospitals, with its inclusion being chiefly for purposes of providing diversion and encouraging socialization Modern dance therapy programs, stressing the importance of the expressive aspects of the dance, have tended to use those dance forms which permit greater freedom and allow greater creativeness on the part of the patient, although social dancing has not been abandoned, and Jurcisin (27) reports it of value with psychotic patients Martin and Beaver (35), working with convalescents, start with *ballroom techniques*, but also make use of simple exercises, *relaxation techniques*, ballet techniques, and others The patients perform individually, in couples, and in small groups, with conversation between patients and between patients, instructors, and observers being encouraged Flaherty and his group (19) also describe a varied approach, in which use of primitive movements and teaching of modern dance fundamentals are included, as well as social, folk, and creative dancing Bainbridge and her collaborators (2) use the "dance mime," a technique which has much in common with psychodrama Bender and Boas (3), May (38), Rosen (49), and Chace

(7) lean toward the modern dance approach, with creativeness and spontaneity being especially encouraged Bender and Boas (3) break down self consciousness and resistance to more primitive types of exercises by having the children practice cartwheels, somersaults, walking on all fours, rolling on the floor, jumping, etc to the rhythm of pounding drums or cymbals, which continue to be used as the children get into real dance activities Some experimenters mention techniques for preventing assaultive behavior while at the same time permitting patients to express their feelings and recognize these feelings Most mention devices for encouraging social contact and integration with the group, such as, for example, the use of the circle

As yet, dance therapy has not advanced to the point where specific rhythms, choreography, and methods of presentation have been delineated in terms of their appropriateness for different types of psychiatric illness Hence, at this time the psychiatric diagnosis cannot carry with it implications for prescription of a certain kind of dance therapy However, progress in this direction is being made It has been determined that dance therapy is especially appropriate for schizophrenic and depressed patients, and there has been some preliminary identification of techniques appropriate for different groups Of special note, in this regard, is the work of Chace (7)

Chace (7) describes a general structure for dance therapy which is essentially as follows (1) There is a preliminary 'warm up' period in which patients move about spontaneously, either alone, with the therapist, or in a group, dancing to music of their own selection, which usually reflects the prevailing mood of the group During this period patients express individualized feelings and fantasies, making initial contacts with each other and with the therapist, and release any excitement which might interfere with the effective structuring of the group (2) The therapist brings the patients together, using waltz music, and the patients in the circle go through various movements, following the lead of the therapist As individual patients initiate their own variations of the movements, the therapist relinquishes leadership to one of those in the group, whom the others copy Leadership moves from one to another As the patients move in unison there is more spontaneous verbalization (3) The final minutes of the session involve a break down into individual or small group movement patterns and a final period of listening to music and conversing Although this general pattern characterizes the sessions for all patient groups, different kinds of music are used for excited and depressed groups, and Chace describes different techniques for contacting patients, allaying anxiety, preventing assaultive behavior, and encouraging expression in different patient groups

What happens in the course of dance therapy is evident from the behavioral descriptions of patients made by therapists and observers of the therapy sessions The following have been mentioned (1) Expression of needs, feelings, fantasies, impulses, and defenses, with communication of

these to the therapist and to other patients, (2) experiencing of physical and psychological contacts with others, (3) gaining of satisfaction through attention and approval from others By means of such experiences various gains have been reported These include (1) Improved poise and coordination (35), (2) increased confidence (27,35,38), (3) increased ability to tolerate contact (7), (4) increase in emotional resonance and spontaneity (2,19), (4) improved ability to relate to others, interest in social activities, and integration in the group (2,7,19,27), (5) increased verbal communication, with consequent improvement in ability to participate in individual psychotherapy (19,49), (6) increased participation in other adjunctive therapies (19), (7) increased insight into personality difficulties (38), and (8) improved ability to deal with reality (19)

Jurcisin (27) reports an experiment in which social dancing was evaluated as a therapeutic medium with long term neuropsychiatric patients Two groups of patients were studied—six in the experimental group and six in the control group The patients were matched not only on the basis of the long term nature of their illness but also on the basis of overprotection or rejection by parents or relatives, little or no dating of the opposite sex, social isolation in childhood, and unhealthy sex education The study was set up to test three hypotheses (1) Social dancing overcomes the patient's inferiority, (2) social dancing stimulates social mixing, (3) social dancing reduces anti social habits Six rating scales were devised for measuring behavioral changes related to the testing of the hypotheses These scales were designated as [illegible]

The groups were observed on the hospital ward before the dance class began, during and after the dance class, and at a ward dance party The dance class met for one hour once a week, for a total of nine weeks Statistical analysis of the findings showed that the control group made no significant improvement in any of the behavior characteristics measured The experimental group showed significant improvement in all areas of behavior on which they were rated, with the exception of "aggressiveness," on which there was no improvement The author attributes the improvement in socialization to the improvement in confidence and comments as follows "Although the social dance experience was terminated, patients continued to participate in dancing at social functions at the hospital They learned a new skill which assisted them in socializing in mixed groups This indicates that social dance is an activity which aids the patient in making a better social adjustment than does an activity which is nonrelated to community life" (27,55)

Most evaluations of dance therapy have been based on observations and case studies, without use of controls Yet, it may be stated with confidence

that this approach is quite effective with some patients, in helping to stimulate psychological growth and to reverse regressive trends

Swimming Therapy

Swimming as an activity therapy for psychiatric patients has attained some popularity and is fast assuming a prominent place in the corrective and recreational therapy programs of many mental hospitals (9,28,29,30,31,48, 53,43) Where this type of treatment is used, it is customary to prescribe and regulate the temperature of the water, length of time in the pool, and activities in the pool in accordance with the needs of individuals and groups of patients (30,43) Although contraindicated for patients with water phobia, cardiac involvements or acute infections (43), swimming therapy has been used with almost all types of psychiatric patients, and even the most regressed patients usually will participate Activities used in the aquatics program include free swimming, various conditioning exercises, races, and games such as water basketball, water volleyball, and water polo (9,43)

It has been claimed that activities such as vigorous kicking and racing in the pool provide a release of energy for hyperactive patients, and that com

Kramer (30) reports on a program of swimming therapy in a Veterans' Administration hospital, with evaluation of the results of such therapy being based on observations made by the therapist and ward personnel For postinsulin patients "it is observed that patients are 'waking up' faster, becoming more alert, and are losing or forgetting some of the unpleasant symtoms such as headache, nausea, sleepiness" (p 19) These patients report that they feel much better after swim therapy, and enjoy much more the social activities following the swimming The patients seem stimulated by the swim therapy, but also relaxed "Aggressive tendencies seem to be under better control and a more social attitude is definitely visible" (p 20) Hyperactive patients seem to be quieter and more manageable after swim class For acutely disturbed patients 'it has been observed that the patients are more relaxed and quite calm after leaving the pool Ward personnel report that since this treatment was introduced fewer aggressive actions by certain *patients have been recorded'* (p 20)

One indication of the value of swimming therapy is evidence that its use results in a decrease in disturbing behavior, reduction in use of restraints, and less need for supplementary sedation for acutely disturbed patients Knudson and Davis (29) present the following statistics on the effects of swimming therapy in Veterans' Administration mental hospitals In a typical hospital the "average number of restraints [was] reduced by 65%, seri-

ous disturbances by 75%, average amount of sedation remarkably reduced, and one less attendant needed on the ward during the day" (p 5)

Research done on the effectiveness of swimming therapy is exemplified by studies made by Timmerman (53) and by Kramer and Bauer (31)

Timmerman (53) reports that 25 disturbed male psychotic patients received a total of 831 'combined' treatments (seclusion, shock, hydrotherapy, and chemical sedations) during a 3 month period when the patients were unable to receive hydrogymnastic therapy These same 25 patients received 523 combined treatments over another 3 month period when hydro gymnastic therapy was available The difference in the number of combined treatments required in the two periods was statistically significant It was concluded that availability of hydrogymnastic therapy contributed substantially to the reduced necessity for other types of treatment

Kramer and Bauer (31) describe a study in which they tested the following hypothesis If free swim therapy and hydrogymnastics can be introduced to the patient the following advantages may occur "(a) a free and voluntary expenditure of excess energy, (b) a physical and social environment which is emotionally satisfying and refreshing, (c) a situation usually conducive to release of tension and the production of relaxation, (d) co operation more easily obtained from the patients, (e) a saving of time for the patient and the therapist' (p 10) In testing this hypothesis 27 patients from acutely disturbed and intensive treatment wards were observed by ward aides for certain forms of behavior—incidents of violence, striking, throwing objects, biting, insulting, aggressive speech making, denunciations, and threats The patients were also interviewed by a clinical psychologist on three occasions, with these interviews being used as a basis for rating on Lorr's Multidimensional Scale for Rating Psychiatric Patients They were rated on six factors—(1) retarded depression versus manic excitement, (2) compliance versus resistiveness, (3) activity level, (4) melancholy agitation, (5) motor disturbances, and (6) submission versus belligerence Ratings were made at two week intervals Following the initial rating, all patients had a two week "wait' period, with no hydrogymnastics After the second rating, 15 patients included in an experimental group had two weeks of hydrogymnastics The 12 controls did not have this treatment The 15 members of the experimental group were compared with the controls, during and at the end of the treatment period, and also with their own status during and at the end of the wait period The results indicated that observations made by ward personnel showed no changes in overt behavior associated with hyperactivity Of the six factors on which the patients were rated by the psychologists, only melancholy agitation showed significant changes, [illegible] was not

[illegible] the psychologist felt that this might have resulted in some bias on his part It

is possible, also, that recognition of this bias may have caused the psychologist to be more conservative in estimating improvement in members of the experimental group

Although the findings of Kramer and Bauer (31) are somewhat equivocal, the preponderance of evidence supports the contention that swimming is a valuable adjunct to the psychiatric treatment program

WEIGHT LIFTING

Studying 100 YMCA male weight lifters and comparing them with 100 other YMCA male athletes on the basis of items on a personality inventory, Thune (52) found that weight lifters tended to be shy, lacking in self-confidence, and unable to obtain satisfaction in the more traditional activities These individuals showed a need to be strong and dominant, and the weight lifting activity seemed to help in meeting this need Corrective therapists in psychiatric hospitals have noted that weight lifting also benefits

achievement (43), and socialization (45,43) Patients engaging in weight lifting appear to enjoy being admired by others and develop increased confidence as they improve (43) Also, the nature of the activity is such that some patients are always resting while others practice It has been observed that those who rest tend to engage in conversation with each other, thus forming relationships with one another In their conversations they often communicate material related to their problems, with the material being such that it can be used therapeutically in other contexts (45,46,43)

Rasch and Freeman (46) describe a program of weight training in a neuropsychiatric hospital and point out its benefits, but indicate that it is not possible to say how much of any patient's improvement is due to this activity and how much of it is due to other aspects of the rehabilitation program They point out, however, that many patients continue the weight lifting after discharge from the hospital and some give it credit for getting them into shape to hold a job

DEVELOPMENT OF EVALUATIVE INSTRUMENTS

Most reports on behavioral changes in psychiatric patients have been based on rather unsystematic observations which do not lend themselves to statistical treatment and often reflect the bias of the observer Some studies (27, 31,40), however, have made use of rating scales of a type permitting quantification of data, and some attempt has been made to eliminate sources of bias (31). At present corrective therapists are recognizing the need for more

objective evaluative instruments, before further progress can be made in research (10,20), and projects to develop such instruments are underway in various hospitals (20)

CONCLUSIONS

On the basis of information now available, the following tentative conclusions with reference to the value of exercise for the rehabilitation of psychiatric patients seem justified

1 Individually prescribed physical exercise as an adjunctive therapy may result in behavioral improvement in psychiatric patients who do not respond well to other therapies
2 Participation in exercise programs may help some patients to profit more from other therapies
3 Participation in exercise therapy in some instances may reduce the need for physical restraints, sedation, and hydrotherapy
4 Emotional rapport between therapist and patient is essential to the success of exercise therapy
5 Further progress in evaluating the contributions of exercise therapy and in developing therapeutic programs depends on the use of research techniques which will make possible clarification of cause effect relationships

NEEDED RESEARCH

Most of the research on the values of physical exercise for rehabilitation of the psychiatric patient has consisted of a trying out of exercise patterns which seemed to make sense on the basis of a sound rationale This type of experimentation has led to the formulation of certain tentative conclusions, which actually probably should be considered as hypotheses There is a need now for (1) the development of better techniques for evaluation of treatment and (2) the completion of more controlled studies Studies need to be made which will enable research workers to evaluate the effects of various sorts of exercise on different types of patient Actually, research of this type is currently being carried on, probably most extensively under the sponsorship of the Veterans' Administration but also in other psychiatric hospital settings

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